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WEATHER PHENOMENA OF THE COLORADO ROCKIES.

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ABSTRACT.

From field observations in the mountain region of Colorado, it was determined that the major portion of the state's moisture is brought in by the winter cyclones. Winter winds redistribute the snow, and Chinook winds remove a portion of it from the mountain region and adjacent plains.

Summer storms of three types tend to redistribute the moisture derived from melting snow. Two types, of almost daily summer occurrence, the regional and local or valley storms, are topographically-confined convection phenomena, which daily transfer small amounts of moisture across divides. Cyclones tend to augment the violence of both other types; anticyclones inhibit the regional storms, but have a negligible effect on the local storms.

Numerous barometric, electrical, and optical phenomena of great interest but minor climatic importance are briefly described. Hypotheses explaining the various major and minor phenomena are presented, and possible applications of the results of this and further studies of mountain weather conditions are suggested.

INTRODUCTION.

Mountain weather, in general, is regarded as unpredictable, not only by visitors to the mountain regions but also by local residents. "Old timers" frequently state that "only fools and flatlanders try to predict mountain weather," and the contrast between actual and predicted mountain weather seemingly confirms the local opinion of weather prophets.

A more careful investigation, however, shows that cyclonic storms having their origin far from the mountains are quite accurately predicted by the methods now in use, while storms

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originating in, near, or between the major mountain ranges cannot be predicted, by present methods, either much in advance, or with any great hope of accuracy.

In this paper, some of the more frequently occurrent weather phenomena of the Colorado Rockies are described, and, where possible, partially explained. The observations here presented should be regarded as a preliminary survey of the problem of Rocky Mountain weather, and not as the final word on that problem.

Observations made by the writer during five years are included in this paper. The magnitude of the area, and the complexity of the phenomena, suggest that several generations of work, by a large number of observers, will be necessary before a complete understanding of the many and complexly-interrelated weather phenomena of the Rocky Mountains is obtained.

While the data contained in this paper were secured in the Colorado Rockies, which are only a small part of the mountainous portion of this continent, the similarity of Colorado mountain weather to that in topographically similar regions elsewhere suggests that conclusions drawn from these field data should apply, with some or much modification, to other mountain regions.

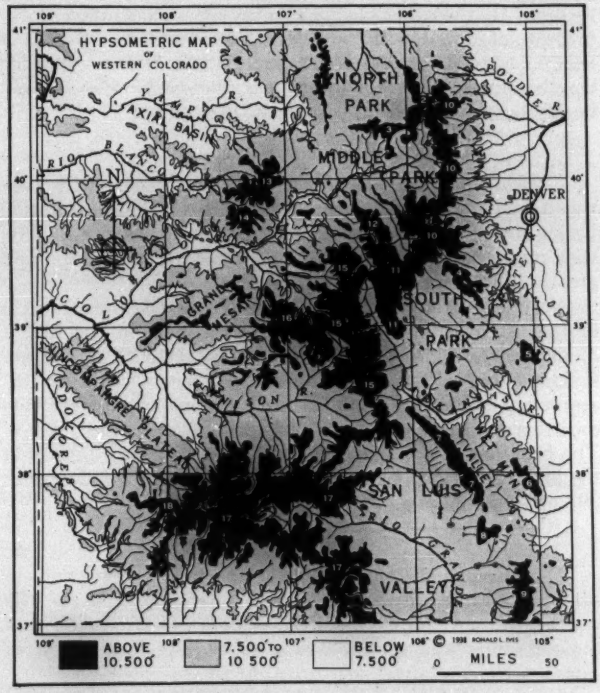
TOPOGRAPHIC SUMMARY.

The Colorado Rockies, a series of very roughly parallel mountain ranges trending slightly west of north and rising to a height nowhere exceeding 14,500 feet above sea level, have a general elevation of 8,000 feet above the plains, and rise approximately 5,000 feet above the intermontane parks.

First upraised from the drying Pierre sea toward the close of Upper Cretaceous time, the Colorado Rockies have been further uplifted a number of times since. (This number is currently in dispute.) Volcanic activity in Eocene and Miocene times altered the topography somewhat; the lava flows, ash and breccia deposits having a general smoothing effect on the topography of the intermontane basins.

Repeated glaciation during Pleistocene time carved the mountains into approximately their present rugged forms, creating deep valleys in what was formerly a rather gently

FIG. 1.



HYPSOMETRIC MAP OF WESTERN COLORADO.

Key to mountain ranges:

1. Rabbit Ears Range.
2. Medicine Bow Range.
3. Never Summer Mountains.
4. Kenosha and Tarryall Mountains.
5. Pike's Peak.
6. Wet Mountains.
7. Sangre de Cristo Mountains.
8. Sierra Blanca.
9. Culebra Range.
10. Front Range.
11. Mosquito Range.
12. Gore Range.
13. Flat Tops.
14. White River Mountains.
15. Sawatch Range.
16. Elk Mountains.
17. San Juan Mountains.
18. San Miguel Mountains.

Topographic data for this map were obtained from the U. S. Geological Survey's *Topographic Map of State of Colorado, 1/500,000;* from long-range photographs; and in a few small areas from field notes. Nomenclature follows U. S. G. S. and Colorado Mountain Club usage.

rolling upland. From the topographic history, it may be assumed that weather phenomena caused or controlled by the presence of mountain masses can have occurred to a greater or lesser degree since Paleocene time, while those controlled by the presence of the deep glacier-carved valleys could hardly have occurred prior to early Pleistocene.[1, 2, 3]

CLIMATIC SUMMARY.

Colorado has an atypical temperate climate, with continental extremes intensified by high altitude. Precipitation varies from less than eight to more than sixty inches annually, with rainfall distribution in the mountains very irregular and greatly influenced by local topography.

Vegetation ranges from possible Upper Sonoran (relict?) in the intermontane basins to Arctic Alpine in the higher mountain areas. Summer temperatures exceeding 110° F. are seldom observed; winter temperatures below minus 40° F. are rarely reported, chiefly because few mountain residents own thermometers capable of indicating lower temperatures. The behavior of gasoline and other "nonfreezing" liquids in the high country suggests that winter temperatures occasionally approach minus 80° F. for short periods.

Seasonal Variations.

The seasonal shifting of the cyclone tracks, northward in summer and southward in winter, definitely affects the weather of the Colorado mountain region, which is well within the cyclone area in winter, and at its southwestern margin in summer.

As a result of the shifting of the cyclone tracks, weather predictions in winter, when cyclonic storms originating far from the mountains are the predominant storm type, tend to be quite accurate; while in the summer, when most storms are of local origin, predictions are frequently erroneous.

Average diurnal temperature range in the mountains reaches a maximum of about 40 degrees (F.) in the summer, declining gradually to less than 20 degrees (F.) in midwinter. Extreme diurnal variations of more than 60 degrees (F.) have been noted, but are not common at elevations of less than 12,000 feet.

Long-period Variations.

Numerous long-period variations in wind direction, precipitation, and annual temperature range have been hypothecated for the Colorado mountain region. In general, the evidence for these changes has been quite nebulous, although minor shifts in the prevailing winds of certain small areas, and some disturbance of the small-scale local storm cycles, have definitely occurred in the past 40 years.[4] Whether these changes are cyclic, progressive, or erratic is not surely indicated by available evidence. That slight changes are now occurring, and have occurred several times in the post-late-Wisconsin past, is definitely proven by variations in the thickness of ice layers in a number of glaciers in and near Rocky Mountain National Park.[5]

The present trend of climatic change in the mountain area of Colorado seems to be toward heavy wet late spring snowfall (1934–35–36–37), wet summers (1935–36), and irregular glacial recession (pre-1900–1937). On the plains east of the mountains, rainfall in the last decade has been slightly less than that during the period of 1900–1928.

Seemingly, wet mountain summers coincide with severe dust storms on the plains. Until more adequate rainfall records, at more closely spaced stations, have been kept for several generations longer, this apparent relation should be regarded as an interesting coincidence.

WINTER STORMS.

Winter storms in the Colorado mountain region may be roughly divided into normal, predictable, cyclonic storms, which bring moisture into the area from "outside"; abnormal, erratic cyclones, not easily or accurately predictable, which usually originate in the Colorado mountains or adjacent parts of the Great Basin region; and Chinook winds, which remove moisture from the leeward slopes and adjacent plains. The prevailing westerly winds of the high country are an important factor in the redistribution of already-fallen snow.

Cyclonic Storms.

During the mountain winter, roughly defined as the period from October 1 to May 1, although it varies in length at

various altitudes, and from year to year, about 25 cyclones, and an approximately equal number of anticyclones, normally pass over the mountain region of Colorado. Of these, about a third are first reported in or near the Aleutian Peninsula. Another third of the cyclones probably originate in the same region, but are not reported until they reach the United States, western Canada, or the Pacific Ocean off the west coast. Most of the non-Aleutian anticyclones are first reported roughly west of San Francisco. A few of the early fall cyclones originate in the Colorado Mountains.

Those cyclonic storms that originate north of latitude 45° and west of longitude 120° are, in general, "well behaved," and the time of their arrival over the mountain region can be predicted with some confidence. Cyclones originating in the mountain region cannot be predicted there with any certainty by methods in use today, for the disturbances preceding a "home grown" cyclonic storm are practically identical with those of a local storm.

Cyclones originating in the Great Basin region, or in areas farther west, but south of latitude 45°, tend to follow extremely irregular courses, at variable speeds, and to be difficult to predict. Probably the broken terrain, extreme diurnal temperature variations and low relative humidity of the Great Basin have a pronounced effect on the upper atmosphere over that region.

Analyses of the barograph, thermograph, and other records of the Denver weather station, for the purpose of determining relations between the various weather factors of the mountain region, have in them an element of futility, for Denver weather is typical of neither the mountains nor the plains.

Comparison of Denver weather with that of the western United States as a whole, however, does shed some light on the problem of mountain weather, despite the "unfortunate" location of the city of Denver. When weather elements of recognizably cyclonic nature are eliminated from consideration, those remaining may be tentatively classified as of mountain origin, and in a few cases, the disturbance of which they are evidence can be roughly traced by referring to the records of coöperating stations in and near the mountains.

The small number and irregular distribution of these

coöperating stations, and particularly the lack of stations on the summits of the various mountain ranges, makes complete analysis of any local weather disturbance difficult and subject to considerable probable error. Coöperating stations are of necessity located at or quite close to settlements, where they can be attended with a minimum of inconvenience to the volunteer observer. On the semi-arid plains, settlements usually occupy atypical areas, where water supply, or shelter, or both, are above average. Hence, no matter how accurate the instruments, or how zealous and skilled the observer, reports from these stations are likely to convey an over-optimistic picture of areal weather conditions.

A careful scrutiny of the weather reports from Colorado, and a comparison of these reports with weather actually encountered there during several winters, shows that more than 80 per cent. of the weather (precipitation, wind, temperature change) can reasonably be attributed to predictable disturbances of a cyclonic nature. About half of the remaining weather is associated with anticyclones that "hang up" over the tangle of mountain ranges near the Colorado-Wyoming-Utah boundaries. A weather station located near Brown's Hole (Fig. 1: lat. 40° 45′ N., long. 108° 50′ W.), at the head of Lodore Canyon, should, in a few years, shed considerable light on the mechanics of "hung" anticyclones.

In this area, the extreme relief (about 4,000 feet from the canyon bottoms to the plateaus, then another 4,000 feet or more from the plateaus to the mountain summits), and the "chimney effect" of the Green River canyons, are sources of continual erratic barometric variation, a possible factor in the delaying of anticyclones that cross the region, and a definite menace to airplane travel, particularly when navigation is by instruments alone.

Chinook Winds.

From one to ten or more times during an average winter, Chinook winds sweep down from the mountains onto the plains at their eastern edge, raising temperatures many degrees in a few hours, removing much or all of the snow, and doing more or less property damage. The temperature changes during a Chinook wind may be logically explained on

the basis of altitude and humidity changes, the difference between observed and theoretical temperatures being minimized when the rehumidification of the wind, during the early part of the storm, by the sublimation of snow on the leeward slopes, is taken into consideration.[6]

While a rapidly-moving barometric low, in many cases, immediately precedes a Chinook wind, the trans-range pressure difference created by it appears inadequate to motivate these violent and long-continued winds.

Many explanations of the causes of Chinook winds have been attempted, most of them on the basis of *areas* of high and low barometric pressure. Unless the atmosphere is assumed to be of uniform cross-section at all times, meteorological reasoning on the basis of areas alone is hardly justified. Chinook winds are definitely three-dimensional phenomena, and search for their cause should likewise be conducted in three dimensions.

Chinook winds are not restricted to the Colorado Front Range area, but occur throughout the Rocky Mountains, and winds closely resembling them have been noted in California and Nevada. The "Washoe Zephyr" of the Comstock region, immortalized by Mark Twain, is perhaps the best known of these.[7]

In considering mountain winds, it should be borne in mind that any surface wind, on crossing a mountain range, undergoes changes in pressure, with accompanying temperature changes. If the humidity also is changed, either by precipitation or evaporation, further changes in air temperature may be expected.

Hence, in the case of a dry wind, blowing from Middle Park (Fig. 1, elevation about 8,000 feet) across the Front Range to the plains (elevation about 5,000 feet), a temperature rise of about 10 degrees (F.) may be expected, and is often observed. Evaporation by the wind, during its transit of the range, reduces its temperature. When precipitation from a moist wind takes place as it crosses the range, a greater temperature rise is called for by theory.

From this, it is apparent that the temperature changes occurring during a Chinook wind differ only in degree from those accompanying any windstorm. If the term Chinook is

confined to violent, dessicating winds from the mountains, not associated with any major cyclone or anticyclone, which cause a temperature rise of more than 30 degrees (F.) in less than 24 hours, much confusion may be avoided. This should be regarded as a working definition, subject to revision as more data are determined.

Minor Phenomena.

A number of phenomena, classified as minor because of the small areal extent of a single occurrence, but of considerable importance in the aggregate, or as indicators of more important weather conditions, have been noted in the Colorado Rockies. Most of these are common to the winter season of all high mountain ranges.

Snow Redistribution.—Mountain snow, driven by high winds, frequently migrates great distances, even across divides, during the winter. With a normal maximum snowfall of only ten feet, many high valleys on the western slopes of the major ranges fill with snow to depths exceeding thirty feet as a result of drifting. Considerable amounts of snow are carried from windward to leeward slopes by the winter winds, giving some eastward-draining streams a greater spring run-off than the direct snowfall on their watersheds would indicate.

Partially offsetting this migration of snow are the actions of Chinook winds, which tend to deposit snow on the windward slopes, and "eat" the snow to leeward.

Most of the existing glaciers in the Front Range area owe their continuing existence to these wind actions. The nevé fields, too small to maintain their dependent glaciers with the accretion from normal snowfall, are augmented by snow blown onto them from the windward side of the range. As the steep-walled cirques are "dead areas" so far as the violent Chinook winds are concerned, nearly all the snow blown into them is retained. Snow piled atop the ice fields by wind also preserves these moribund glaciers by forming a protective blanket on their upper surfaces which, as a result, are not exposed until late in the mountain summer.

In extremely favorable years, when the accretion due to snowfall and drifting is great, or melting is slight, or both, some of the snow blanket on the ice surface survives the

mountain summer, and becomes an integral part of the ice field.

During a mountain winter, with its succession of storms, snow may be carried great distances in a series of "jumps." The normal westerly and northwesterly winds transfer it from the western to the eastern slopes of the ranges, while the Chinooks tend to dessicate the eastern slopes, only to drop

FIG. 2.

CLOUD VEIL WEST OF BOULDER, COLORADO.

Photographed from the University of Colorado campus at 10 A.M., Feb. 7, 1935. Temperatures in Boulder, elevation about 5,300 feet, were about 38 degrees (F.) at that time. One hour later, a resident of the foothills, 4 miles west of Boulder and about 3,000 feet higher, reported by telephone that his thermometer had been standing at 16 degrees for several hours. During the next six hours, while the cloud veil slowly diminished in size and finally disappeared, temperatures in Boulder dropped 48 degrees.

the acquired moisture again, usually as snow, on encountering the western slope of the next major mountain range.

Cloud Veils.—Cloud veils, a picturesque feature of the foothills region during many winter days, are locally regarded as precursors of Chinook winds. A more careful investigation shows that they indicate thermal stratification of the air, and are precursors only of temperature change.

Cloud veils indicate the contact between cold and warm air strata, and are practically identical in appearance whether the cold air stratum is above the warm, or below it.

Conditions necessary for the formation of a cloud veil are still air, and a temperature difference between two adjacent air strata sufficient to produce condensation at their contact.

It seems probable, from a study of weather conditions following the appearance of cloud veils where the foothills drop off abruptly to join the plains, that the air stratum apparently

FIG. 3.

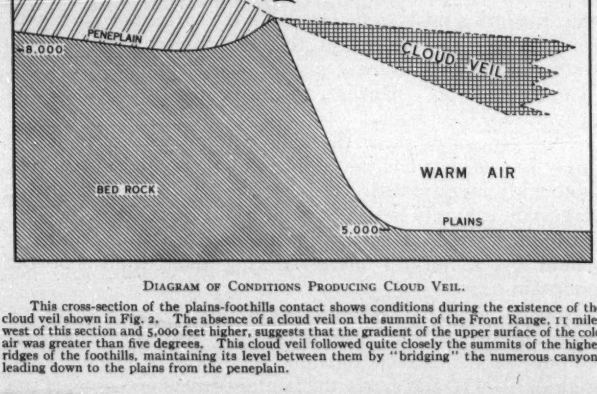


DIAGRAM OF CONDITIONS PRODUCING CLOUD VEIL.

This cross-section of the plains-foothills contact shows conditions during the existence of the cloud veil shown in Fig. 2. The absence of a cloud veil on the summit of the Front Range, 11 miles west of this section and 5,000 feet higher, suggests that the gradient of the upper surface of the cold air was greater than five degrees. This cloud veil followed quite closely the summits of the higher ridges of the foothills, maintaining its level between them by "bridging" the numerous canyons leading down to the plains from the peneplain.

causing the cloud veil is actually the wedgelike leading edge of an invading air mass which has been elevated by crossing the mountains.

Temperature Inversions.—Isolated strata of abnormally warm or cold air, sandwiched between layers of air of approximately normal temperature, are so frequently encountered, usually by accident, in the mountain region that they may reasonably be assumed of almost daily occurrence.

In most instances, there is no visual indication of the sharply defined warm or cold air stratum, so that, unless it is

actually encountered by a mountaineer or aviator, it will pass completely unnoticed.

Frequently an "inversion" of this kind will last for some time, a "warm zone" or "cold zone" being noted part way up a mountain peak for several successive days, even in quite windy weather.

It seems probable that these thermally-variant air strata are related to the "vanishing rains" so often reported by residents of the plains region just east of the mountains. Rain is seen falling from clouds at a great elevation, such as 10,000 feet, but the moisture fails to reach the ground in the area under the cloud. When observed from the crest of a nearby mountain range, the rain definitely falls from the cloud, and drops normally for several thousand feet, then vanishes into a misty zone far above the surface of the plains. A warm dry air stratum at this "vanishing point" would account for this seemingly mysterious phenomenon. These "vanishing rains," likewise, might be used as evidence of temperature inversions.

The genesis of these thermally-variant air strata is not surely known, nor has the problem of their origin been very thoroughly investigated. It is here suggested (although the suggestion is hardly better than a careful guess) that they are relict air masses, of small dimensions, torn from, and left behind by, major air masses during their transit of the mountain region.

Lunar Coronas.—During many nights of the year, in the mountain region, but most commonly during the winter, rainbow-colored coronas surround the moon, occasionally the brighter planets, and rarely the fainter planets and some of the brighter stars. These coronas are most common when high-country temperatures are abnormally low, and are locally, with some correctness, regarded as precursors of a cold wave.

In Boulder, Colorado, during a cold spell in December, 1932, a lunar corona was observed for eleven successive nights. This is an extreme case, but one corona a week from October to May is not an abnormal frequency at that location.

These lunar coronas have been variously attributed to water droplets and to ice crystals suspended in the air.[8] Seemingly "filling half the sky," these coronas, when meas-

ured, are actually quite small, having a measured diameter of less than 25 degrees. At times, a small corona, having a diameter of not over 5 degrees, has also been noted, and rarely, both types are present simultaneously. The angle subtended by a corona is constant, but apparently decreases as the celestial body illuminating its cause rises from the horizon toward the zenith. The brilliance, also, in most cases, diminishes greatly when the light source rises to much more than 30 degrees above the horizon. (All of these measurements were made with a Brunton compass, unsuited for night use, and may be in error 10 per cent. either way.) The brilliance of a large corona, as determined from a photographic plate, may be as much as 1/10 that of the moon. (This figure is correct only to a factor of two.)

Sun Dogs.—Sun dogs, mock suns, solar halos and coronas are rather common features of the winter sky, occurring half a dozen times during an average winter. Completely-developed halo displays, complete with mock suns and side arcs, are less common, occurring not more than twice a winter. While their appearance is unpredictable, displays of this kind are most common during the early morning hours, while the sun is less than 45 degrees above the horizon, and in abnormally cold weather, when the air-suspended ice crystals necessary for their appearance are most numerous.[9] No two successive solar halo displays are either identical or very similar.

At Boulder, Colorado (lat. 40 degrees N.), the following observations were made, chiefly during notably unsuccessful attempts to photograph solar halo displays. The outer limits of the outermost visible side arcs were slightly more than 60 degrees away from the sun in two observed displays; slightly more than 40 degrees in three other cases. The vertical extent of the display (horizon to upper limit of highest visible arc) was less than 90 degrees in every case. Measurements of light intensity with a modified Weston Photronic Exposure Meter, hardly suited to the task, gave decidedly unsatisfactory results. "North light," however, could be rather accurately measured, and decreased from 250 F.C. while the display was visible to just under 200 F.C. after it faded out. Normally, as the sun rises, "north light" increases slightly in intensity. (The above figures are accurate to plus or minus 10 per cent.)

Ice Haze.—Minute crystals of ice, suspended in the winter air, frequently introduce ice haze, a phenomenon more apparent to the photographic plate than to the eye. Normally, the range of a camera using infra-red-sensitive plates and the necessary accompanying filters is limited only by the horizon, although definition falls off slightly about 25 miles from the camera because of atmospheric turbulence and possibly from the scattering of infra-red light by large droplets of water and dust particles. In very cold weather, objects ten miles from the camera are slightly obscured by white haze, and their images on the plate slightly diffused. The ultimate range of the camera under these conditions is about 40 miles. Beyond this distance, everything "whites out." During weather of this kind, a panchromatic film, used with a light yellow filter (Wratten K-2), actually has a greater range than an infra-red-sensitive plate used with its filter. It would seem, from this, that ice crystals have the property of diffusing and reflecting light from both ends of the spectrum, with a minimum of diffusion roughly in its center.

It should be noted that both photographic films and gelatine filters (however mounted) act abnormally at temperatures of more than about 20 degrees below zero; films becoming brittle and somewhat erratic as to exposure, filters suffering from microscopic reticulation in the cement, which causes mild to severe diffusion of the image. Extreme cold also has a somewhat unfortunate effect on some lenses. Filter reticulation caused by cold may or may not "heal" when the filter is warmed up to room temperature.

"*Snow Static.*"—Static electrical disturbances, chiefly noted as interrupters of telephone, telegraph, and radio communication, are common during the mountain winter, although no thunderstorms occur within several hundred miles of the disturbed region. These "static storms" are most intense during very cold weather when "sharp" snow is being blown around rather violently. Wire fences on the plains near the mountains frequently accumulate charges strong enough to knock over men or cattle, and sometimes spit sparks to nearby grounded objects. Plains residents occasionally report sparks that jump as much as a yard from their fences. Experiments with several long, well-insulated wire

fences failed to produce sparks more than four inches in length. A static charge producing a spark only one inch long is powerful enough not only to knock a man down, but to make him quite sick for several hours after he regains his feet.

During snowstorms, in cold weather, radio programs received in the mountain region are quite often blanketed by a steady low-pitched growling noise, quite similar to the drumming of a heavy rain on a wooden roof. This noise is locally attributed to the snowfall, it being hypothecated that minute static discharges take place as the snowflakes touch grounded objects. This disturbance is present whether the radio antenna is outdoors or in, and whether the receiver is powered from the transmission line or from batteries. Similar disturbances can be heard during some snowstorms by listening in on the rural open-wire telephone lines, or by connecting a headset between any two medium-sized metal objects, such as a stove and a bedspring.

INTERMEDIATE SEASONS.

The intermediate seasons, spring and fall, separating winter and summer, cannot be accurately defined by reference to a calendar, even when corrections for altitude are made, but are definitely determined by marked and abrupt "breaks" in the weather. The mountain spring, a period of about two weeks, may occur at any time between May 10 and June 20, and is characterized by a "run" of clear days. As a result of this clear weather, melting in the high country progresses rapidly, and floods of greater or lesser severity may be expected on the plains and in the intermontane parks. The beginning of spring very roughly coincides with the northward shifting of the cyclone tracks, while the end of spring and the beginning of summer is marked by the commencement of the summer cycle of regional and local storms.

Fall, in the mountains, is likewise characterized by a "run" of clear days, but is not so sharply defined as the mountain spring. Fall usually begins toward the end of August with a "real" snowstorm, followed by from three days to four weeks of clear cold weather. Fall ends with a heavy snowstorm, which lays down the "permanent" snow of that season.

The beginning of fall almost exactly coincides with the cessation of the local and regional summer storms, and ends with the coming of the winter cyclones and anticyclones.

The popular classification of spring and fall as definite seasons seems hardly justified in the mountain region, where these two "seasons" are actually short periods of transition between cyclonically-controlled and locally-controlled weather phenomena.

SUMMER STORMS.

Throughout the Rocky Mountain region, summer storms are of almost daily occurrence, and are called, in various places, the "afternoon storms," the "two o'clock storms," or are named from the place of their apparent origin, as "Taylor Park Storms."

Field studies of mountain storms during five summers show that many different types of storms occurred, and a number of classifications, most of them extremely complex, are possible. Classification of Rocky Mountain summer storms by three general types, which probably occur in most glaciated mountain regions, was decided upon, on the basis of origin. These types are:

1. *Cyclonic Storms, of extramontane origin.*

2. *Regional Storms, of mountain origin, generally confined to one of the parks or intermontane basins, and influencing areas of the order of 10,000 square miles.*

3. *Valley Storms, usually originating in, and confined to, one system of valleys. These storms influence an area of the order of 200 square miles.*

Regional storms, from their mechanics, should, at least theoretically, occur to some degree in any mountainous region containing broad intermontane basins, regardless of altitude, latitude, or other geographic factors.

Valley storms should not be expected in regions of "smooth" mountains, where glaciation or intense recent erosion has not taken place. Steep gradients seem necessary for their occurrence.

Several storms of the same type may occur simultaneously in adjacent topographic areas, seemingly without mutual interference. These similar simultaneous storms may be

classed as a single storm over the whole area concerned, or may be considered singly, on the basis of moisture origin. The latter seems the more logical method, for if the storm over one area is inhibited, storms over adjacent regions, unless also interfered with, proceed normally.

Frequently, storms of two or more types will occur together, causing a violent storm, locally, and aptly, called, by its effects, a "trash-mover and a gully-washer." Storms of each type have a definite, although usually minor, effect on storms of other types occurring in the same general area within the succeeding 24 hours. "Pure cases" of any storm type are quite rare during the summer season.

Cyclonic Storms.

Major cyclones and anticyclones are infrequent during the summer season in the Colorado Rockies, and may be classified, with reasonable correctness, as abnormal phenomena. The regular cyclone tracks are a considerable distance north of the Colorado-Wyoming line during most of this season.

Even though they are abnormal, summer cyclones of distant origin can be, and usually are, predicted with some accuracy by methods now in use. Cluttering of the records by local disturbances, and interference with the normal progress of cyclones by phenomena not affecting the recording instruments, are the probably cause of most of the prediction failures.

Cyclones of supposedly local origin, first reported over southwestern Colorado, are the "black sheep" of forecasting, arriving at the first point of observation simultaneously with the barometric disturbances they induce, and passing so few stations in their erratic progress that their course cannot be accurately plotted until they have reached, or passed over some miles of, the plains. Many of these cyclones, originating, supposedly, in southwestern Colorado, have a life of only 18 to 24 hours, and vanish somewhere over Kansas or Nebraska.

Observations of storms in the San Juan and San Miguel Mountains, reputed place of origin of some of these "home grown" cyclones, by field workers of the U. S. Geological

Survey and by Colorado Mountain Club parties, suggest that the true place of origin of these storms is not in the mountains, but in the canyon-trenched plateauland of the "four corners" country of southeastern Utah.

This region, not only at the contact of the mountains with the plateaus, but also near the southern limit of the cyclone belt and the northern limit of the monsoonlike southwestern storms, is a critical, and at present, almost unstudied area. Continuous observations at several stations between the Colorado-Utah line and Natural Bridges National Monument, for a period of at least several years, and preferable for several decades, seem to offer the best method of determining the true origin of these atypical cyclones.

Major cyclones and anticyclones, while usually foreign to the mountain area, are definitely affected by topographically-induced convections as they pass over the mountain region. Rainstorms (and occasionally snows), predicted and even sighted from the plains, are often "hung up" at the crest of the Front Range by the sheet of rising warm air resulting from intense heating of the flatlands adjacent to the mountains. It seems probable that many of the rains so fervently prayed for in the dustbowl are disappointingly light because the moisture-laden air from "outside" has been diluted with hot desiccated air rising from the very region that most needs the rain. Like the proverbial snowball rolling downhill, this condition seems to get worse the longer the drought continues, and leads to an apparent shifting of precipitation from the plains to the mountain region. This shift was particularly notable in the summer of 1936, when for days at a time it rained steadily in the mountains, while the only precipitation on the plains was choking yellow dust.

From these observations, it may be hypothecated that the total annual precipitation in Colorado is much more constant than the rainfall records, mostly based on plains precipitation, indicate. As most of the effective mountain precipitation eventually reaches the Colorado River drainage, this seeming inverse relation between mountain and plains precipitation is of considerable importance at the present time, when a number of transmountain water diversion projects are under consideration. If rainfall measurements show that a water shortage on

the plains, chiefly in the Platte and Arkansas drainages, is actually accompanied by increased precipitation at the headwaters of streams draining into the Colorado, then transmountain diversion projects should be effective in ameliorating the recurrent water shortages in the sugar beet country of the plains. If, however, the inverse relation of mountain to plains precipitation is found by detailed measurements to be more apparent than real, the value of some of these transmountain diversion projects is definitely open to question.

Cyclones, in general, tend to increase the intensity of local storms, upset their normally rather regular timing, and lower the temperatures, occasionally changing the "daily rain" to a summer blizzard. Anticyclones, on the other hand, have an inhibitory effect on local storms, *for one day only*. After causing one clear day, an anticyclone, however long it may hover over the mountain region, has no further observable effect on the local summer storms.

Regional Storms.

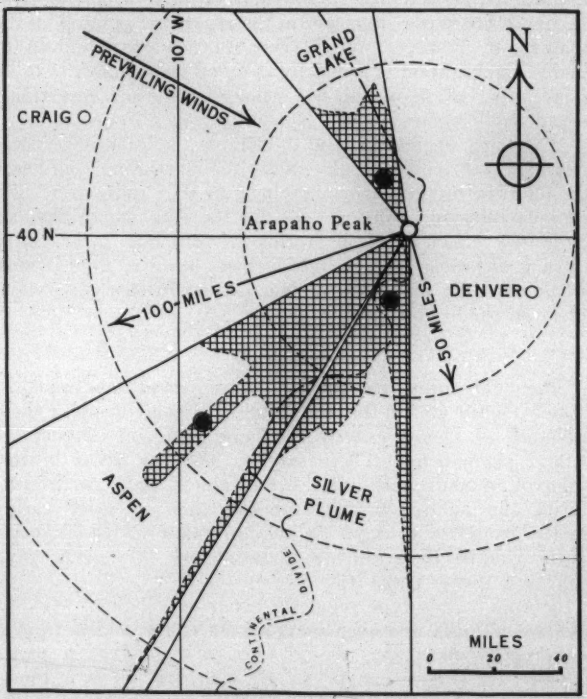
Regional storms, securing the major part of their moisture from a definite area in the mountain region, and dropping their moisture on almost exactly the same area, are convection-caused phenomena. These storms, affecting areas of the order of 10,000 square miles, are of almost daily occurrence during the summer season, although their intensity varies greatly from day to day. In the aptly-descriptive language of the Middle Park rancher, these storms "try every day, but don't always make it."

Storms of this type regularly occur over North, Middle, and South Parks, and over the San Luis Valley, which, from a topographic viewpoint, should also be classed as a park. Taylor Park (Fig. 1, lat. 38° 50′ N., long. 106° 35′ W.), topographically intermediate between a true park and the melting basin of a relatively large extinct glacier system, has its own series of storms, not easily fitted into any of the classifications previously set up.[10]

While each park, with its largely self-contained storms, is a separate case, not exactly resembling any other, the general mechanics of the regional storms is basically the same wherever they have been observed. More than 200 storms of this

type were encountered in the field during the summers of 1932–1936, inclusive, as well as a number of somewhat

FIG. 4.



AREAS VISIBLE IN FIGS. 5, 6, AND 7.

The shaded areas on this map correspond to the photographed areas in the three following figures (Figs. 5, 6, and 7). The dotted boundary of each field sector represents the horizon in its respective photograph. High altitude sky features far beyond the land horizon, are, of course, visible in each photograph. Although the theoretical limit of the range of a camera is infinity, atmospheric haze and aerial turbulence limit the practical range through the atmosphere, even with the infra-red-sensitive plates used in making these figures, to about 300 miles. Curvature of the earth and broken topography limit the range, for land features, to about 160 miles, in the Colorado Rockies.

atypical storms, probably, but not certainly, regional. It is entirely possible that some of these atypical regional storms

were, in reality, unrecognized "compound storms," with the effect of the disturbing storm component of rather small magnitude compared to that of the regional component. Available facilities have not, to date, permitted a study of these "compound storms."

Typical Regional Storm.—Regional storms are usually quite similar in their various manifestations, the intensity of occurrences, rather than their sequence, being the major variable.

A typical storm seemingly starts before sunrise, when a thin haze, normally not extending more than a few feet above the ground, appears in the lower parts of the intermontane basin or park. From the previous midnight until dust begins blowing shortly after sunrise (this is the normal "vagrant" dust of a semi-arid region, not to be confused with the dense clouds of dust comprising a dust storm), the sky is intensely clear over the parks, even an infra-red photograph failing to reveal the faintest trace of a cloud. During this time, the surface air is still, humid and cool.

About an hour after sunrise, the haze disappears, and as the air becomes warmer and drier, "vagrant" dust begins to blow. A few very tenuous cirrus clouds, surrounded by a faint white nebulosity, possibly suspended ice crystals, appear very high in the air (above 17,000 feet), and slowly drift across the sky from west to east, apparently unaffected by the regional and valley storms which occur later in the day. Probably these clouds have no connection with the regional storms, the cirrus level being far above the normal upper limit of convection.

Two hours, more or less, after sunrise, a few small cumuli appear at various locations over the park (Fig. 5), at a medium elevation (14,000–16,000 feet, and increase in size and opacity as they slowly drift across the sky toward the east and southeast. These local cumuli tend to "pile up" in the southeastern quadrant of the park, until the sky is about 75 per cent. obscured.

This accumulation of clouds continues until mid-afternoon, the portion of the sky 75 per cent. obscured varying from storm to storm. A rapid cooling of about 20 degrees (F.) takes place on the surface under the clouded sky area.

As the clouds "pile up" at the eastern and southeastern margins of the park, they have a typical "en echelon" appearance, and their lower surfaces lie in a definite "plane." Aviators report that the upper surface also is "a plane, with holes in it."

FIG. 5.

SMALL CUMULI AND CIRRI OVER NORTHWEST QUADRANT OF MIDDLE PARK.

The cumuli in this picture are riding a moving air stratum at an elevation of between 14,000 and 16,000 feet with a velocity of less than 30 miles per hour. The cirri, which have been "fuzzed" by their very rapid motion, have an elevation in excess of 17,000 feet. This photograph, taken from Arapaho Peak, 13,500 feet above sea level, with an infra-red plate, includes parts of the Park and Never Summer Ranges (Fig. 1, numbers 2 and 3) and the glaciated valley of the upper Colorado. This area is contained in the "Grand Lake" sector of Fig. 4. The cloud conditions here shown first appear about two hours after sunrise, and last for varying periods, the exact time depending on the quadrant of the park they are over and the intensity of the storm. This photograph was taken at 2:30 P.M. on August 3, 1935.

Between two and four in the afternoon, the clouds become very black, changing from cumuli to cumulo-nimbi, obscuring the whole sky. During this change, which progresses from the edges of the clouded area inward toward the center, a definite disturbed zone appears wherever clouds have crowded out over a mountain range. This disturbed zone is almost certainly the result of the interaction of the prevailing winds, which

tend to drive the clouds eastward, the thermal expansion of the entire aerial content of the park, and the convection currents almost universally present on a mountain slope. The disturbed zone follows very roughly the crest line of the range, but is not visibly influenced by minor topographic features, such as passes or extra-high peaks (Fig. 6).

With the change of cloud type over much of the park from cumulus to cumulo-nimbus, there is a general quieting of the air within the park, and an increase in the volume of the disturbed zone. From it, small dense black scud clouds move rapidly away from the main cloud mass, and gyrate wildly in the formerly clear air on the leeward side of the mountain range. Thunder and lightning occur, almost invariably, but are largely confined to the disturbed zone and the scud clouds.

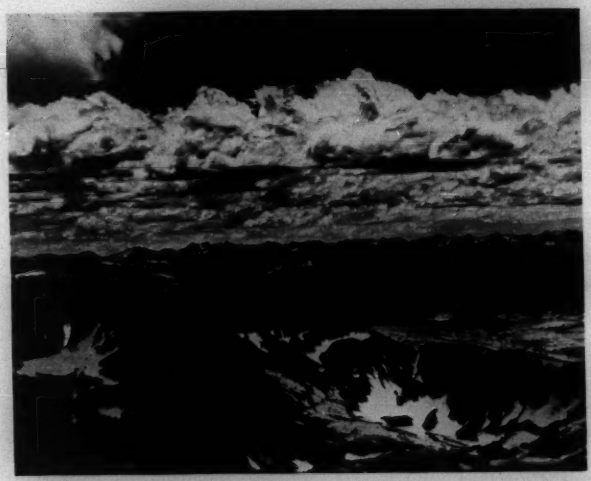
This period of calm in the valley and turbulence on the heights may last from a few minutes to over an hour, during which time pressures indicated by a barometer on any high point vary rapidly, repeatedly, and irregularly from extremely high to extremely low for the particular altitude.

The premonitory calm ends suddenly with violent erratic winds and intense downpours from the scud clouds, followed by heavy rain from the disturbed zone (Fig. 7). Within a few minutes, moderate rain falls from the entire mass of cumulonimbi. Hail is a common occurrence in the mountains during the rainy phase of a regional storm, but is not necessarily an indication that raindrops have been carried to any very great height by rising air currents. With air temperatures at 13,500 feet only 40 degrees (F.) when the sky is overcast (they often go below freezing in the late evening), a raindrop need only be lifted about 2,500 feet to enter a stratum of freezing temperature. The necessary elevation is about that of the upper "plane" of the regional cloud stratum.

During the rainy phase of a regional storm, some of its clouds may "escape" from the area over the park by crossing the mountain rim, and travel with the wind for distances as great as forty miles, dropping some moisture during their wanderings. The elevation of these "escaped" clouds decreases immediately they have crossed the mountains, and averages only about 2,000 feet above the general surface (Fig. 8).

After rather violent precipitation usually lasting for about fifteen minutes, but occasionally continuing for as long as two hours, the clouds rather suddenly "break" and dissolve in a very few minutes. The sun comes out, and rapid evaporation of the newly-fallen rain takes place. An hour or

FIG. 6.



CUMULI EN ECHELON OVER SOUTHWEST QUADRANT OF MIDDLE PARK.

The cumuli here are "piling up" in the south and southwest portions of Middle Park. Their elevation is between 14,000 and 16,000 feet. One small cloud mass in the upper left corner of this picture has been torn loose from the main mass by rising air currents, and forms the extreme western margin of the "disturbed zone" over the Front Range. This photograph, taken within a few seconds of Fig. 5, from the same location (the camera was merely turned on the panning head of the tripod), includes parts of the Gore, Sawatch, Mosquite and Front Ranges (Fig. 1, numbers 12, 15, 11, and 10) and is the Aspen sector in Fig. 4. The long valley in the middle distance is that of the Fraser River, a tributary of the Colorado. Beyond the valley are the Vasquez Mountains, a glacier-fretted minor range.

so of cool clear weather generally intervenes between the ending of the regional storm and sunset.

While the regional storm is going on, storms of lesser magnitude—the valley storms—also occur, not necessarily in exact synchronism with the regional storms, and apparently uninfluenced by them except at the extreme heads of the valleys, where interference between storms takes place.

Effect of Cyclones and Anticyclones.—Cyclones and anticyclones of major proportions have a definite and partially predictable effect on the regional storms of the Colorado Rockies.

Cyclones, in general, bring about a lowering of the temperature, detectable in the lower parts of a park, and pronounced on the mountains surrounding it. This leads to an increase in cloudiness, and a lowering of the level of the clouds of a regional storm by several hundred, or, in extreme cases, several thousand, feet. This lowering brings the bottom of the cloud stratum below the summit of the valley wall, confining the storm even more rigidly than do the rising air currents present on days of normal weather. The timing of the regional storms is, as a result of this shifting of the cloud level and lowering of the temperature, completely disrupted, and on days when cyclones pass over the mountain region, the rains may begin before noon, and continue until long after sunset.

With the downward shifting of the normal regional cloud level, the regional and valley storms mutually interfere, so that differentiation between clouds or precipitation of the two storm types is well-nigh impossible. If, in addition, as often occurs, the cyclone is accompanied by a mass of clouds from "outside," the tangle of interfering storms is practically beyond analysis, and almost anything may happen. It is these "mixed storms" that bring summer blizzards with thunder and lightning to the mountain region, and cause other seemingly anomalous phenomena.

Anticyclones, normally bringing warm air into the mountain region, tend to inhibit the daily regional storms, and bring about a totally clear day. Warming caused by anticyclones is slight at low elevations, but considerable on the heights surrounding the parks. The temperature rise produced by an anticyclone sometimes amounts to 15 degrees (F.) at 14,000 feet.

The normal "closed circuit" of air and moisture circulation in the parks is changed to an "open circuit" by the alteration in thermal gradient induced by an anticyclone. Heated and moistened air from a park, under these conditions, no longer stops rising at altitudes of from 14,000 to 16,000 feet, but

ascends several thousand feet higher, mixes with the eastward-moving air of the "trade wind" stratum, and is carried rapidly away from the area of its origin. This results in a dessication of the parks, and a temporary reduction in the total weight of air confined between their walls.

Partially offsetting this air and moisture removal are the valley breezes that spring up during the evening of a clear day, and the accelerated melting of mountain snowfields caused by three or more additional hours of strong sunshine during the hottest part of the anticyclone-induced clear day.

Usually, an anticyclone causes only one day of clear sky, after which the thermal gradient, although not the average temperature, returns to normal, and the regional storms start again, often rather feebly, with the regional cloud stratum several hundred feet higher than usual.

It is commonly stated that anticyclones inhibit convection, but their primary effect on mountain storms seems to be an inhibition of condensation at normal levels, with a resultant reduction of precipitation and an increase in effective insolation.

Areal Variations in Regional Storms.—No two parks in the Rocky Mountain region are topographically identical. Each park has its own outline, depth, and wall gradient, and all of these factors have a definite, although not always important, effect on the storms originating in the parks, and largely occurring over them.

In general, a topographic map of a park drawn to a scale of one inch to ten miles, with a contour interval of 1,000 feet, shows all the features that influence regional storms.

Viewed only from the standpoint of regional storms, North and Middle Parks (Fig. 1) are the most perfectly bowl-shaped, and in them the storms behave in the most consistent manner.

South Park, with a topographic opening to the east, is a rather imperfect bowl, but the storms there closely resemble those in the two parks farther north, with the exception that a greater number of storms "escape" to the east.

Taylor Park, previously mentioned, is not a typical park at all, and does not, as a result, have storms closely resembling those typical of the true parks.

The San Luis Valley, topographically a park, has regional storms that differ considerably from those in the other parks, because of differences in latitude, air currents, water supply and valley wall gradient. Here, the water supply is chiefly from the San Juan Mountains, with small additions of moisture from the Sangre de Cristo, Blanca and Culebra

FIG. 7.

DISTURBED ZONE BETWEEN MIDDLE PARK AND THE PLAINS.

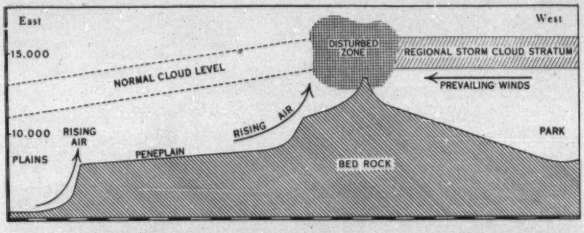
Cumulo-nimbi in the left half of this picture are being violently tossed about by the air currents rising from the plains 8,000 feet below the peaks and fifteen miles to the east (note motion during exposure). At the right are the cumuli over Middle Park. In the center, on the horizon, over Gray's and Torrey's Peaks, is a violent rain and hail storm, associated with the regional storm over Middle Park. In the far distance, to the right, are the cumuli of the regional storm over South Park, which "broke" within a few minutes of that over Middle Park. This picture, the "Silver Plume" sector of Fig. 4, shows about 60 miles of the Front Range (Fig. 1, number 10), from Arapaho Peaks south. This photograph was taken immediately after Figs. 5 and 6, from the same tripod setup. The storm here shown caused precipitation over the Denver area as well as in the parks.

Ranges (Fig. 1, numbers 17, 7, 8, and 9). With a lesser average relative humidity, condensation in air rising from the valley, which is almost a desert basin, with scanty arid vegetation, playas, sand dunes and blind drainages, does not take place at 14,000–16,000 feet. Evaporation-moistened air rises to great heights, where it mixes with the eastward-moving air of the "trade wind" stratum, and travels rapidly toward

the eastern wall of the valley. There, it is uplifted by the rising valley-wall air currents, and a few miles further east is uplifted again by updrafts originating on the plains, and following the eastern face of the Wet Mountains (Fig. 1, number 6). This leads to heavy precipitation in the Wet Mountain Valley, the "La Mojada" of the old Spanish maps. Between the air currents rising from the San Luis Valley and those from the plains, there is a minor "closed circuit" system of storms over the Wet Mountain Valley.

The normal mechanics of the "daily storms" originating in the San Luis Valley closely resembles that of the other park storms during the first day of an anticyclone. The ultimate

FIG. 8.



CROSS-SECTION OF THE FRONT RANGE DURING A REGIONAL STORM.

Conditions shown diagrammatically in this figure are similar to those shown photographically in Fig. 7. Minor air currents are not shown and topography has been generalized for the sake of clarity. Horizontal intervals are one mile each; vertical intervals are one thousand feet each.

effect of the daily heating is one of dessication in the San Luis Valley, while in the other parks much of the evaporated moisture is regularly restored to its approximate source.

Given a greater water supply, perhaps triple the present amount, it seems probable that the regional storms originating in the San Luis Valley would drop their moisture back into the valley, and closely resemble those originating over the other parks.

The region of the headwaters of the Gunnison River (Fig. 1) somewhat resembles a park, but does not have any very regular regional storms, due perhaps to the openness of the basin to the west. Erratic and unpredictable squalls are common in this area, and a strong "chimney current"

usually blows up the valley some feet above its floor, carrying evaporated water upward and eastward beyond the topographic confines of the upper Gunnison Valley. It seems probable, although good evidence is lacking, that some moisture of Gunnison Valley origin eventually falls as rain in the Wet Mountain Valley.

Progressive Seasonal Variations.—While strictly confined to the mountain summer, regional storms are not of uniform intensity during that season. In general, their intensity reaches a maximum during early July, after which they gradually "run down" and occasionally "miss" as the season progresses.

These intensity variations may be attributed to several factors, of which the two most important seem to be the decrease in available water as the summer goes on, and the lessening of insolation occurring at the same time. With less water to evaporate and less energy available for evaporation, the amount of water evaporated rapidly decreases, as does the regional precipitation, which is largely of local origin.

While decreased precipitation is a clue to the "wearing out" of these storms, a better criterion is the absence of the afternoon cloud bank when other conditions are normal. This almost never occurs until the parks are thoroughly desiccated, strongly suggesting that lack of water, rather than some other, as yet undetermined, force is inhibiting the regional storms.

As might be expected, the storms in the San Luis Valley, the southernmost park in the area under consideration, are the first to stop from lack of moisture. Later, those of South Park become erratic, and sometimes cease. Regional storms over Middle and North Parks usually continue until the end of the mountain summer, with some or much decline in daily precipitation.

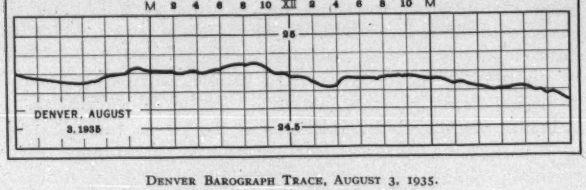
When a regional storm "misses" from lack of water, the condition tends to be self-rectifying, for additional insolation received by the mountain region during the wholly clear day accelerates melting of the snowfields, with a resulting increased supply of water to streams flowing into the park. In the event that all the mountain snows are melted, as usually occurs in midsummer on the margins of the San Luis Valley

and often around South Park, only moisture received from "outside" will revive the regional storms.

Interference Between Regional Storms.—It is commonly believed in the Colorado Rockies that the regional storms are a single storm, occurring over the whole mountain region. This view is quite logical, and is seemingly supported by field observations until the storm over a single park "misses" because of water shortage or an anticyclone over that park, while storms over other parks occur with their normal intensity at their regular time of day.

Close observation of the storms in two adjacent parks from the divide between them discloses that the storms over

FIG. 9.



DENVER BAROGRAPH TRACE, AUGUST 3, 1935.
(Data from U. S. Weather Bureau.)

The barometric variations here shown reflect the disturbances in the mountains, 40 miles west of Denver, during the regional storms shown in Figs. 5, 6, and 7. At the same time, an aneriod in the mountains (on Arapaho Peak) showed no such regular dip and rise as this, but "jittered" rapidly up and down, probably as a result of purely local air disturbances.

In Boulder, 30 miles northwest of Denver, the barometer declined and rose similarly to that in Denver, but the minor humps and hollows in the curve, attributed to local disturbances, were not identical.

the two parks do not necessarily "break" at exactly the same time, although one usually does not lag more than half an hour behind the other.

Interference between simultaneous or nearly simultaneous regional storms in adjacent areas apparently does not occur, the rising air currents along the park walls effectively isolating the main mass of clouds over one park from that over another. In the disturbed zone, over the mountain rims of the parks, some mingling of storm clouds does take place, but the very forces that create this disturbed zone also seem to isolate it effectively from the major cloud masses.

A slight "cascade effect" has been noted in west central Colorado, where valley storms on the Western Slope "break"

early in the day, and some of their "escaped" clouds creep eastward across the ranges to join the regional cloud masses over the parks. This may increase the moisture suspended over the parks by as much as one percent, which is about equal to the moisture loss caused by the "escape" of regional storm clouds eastward toward the plains.

Aerial Stratification.—It is apparent, from field observations, that storms of various types are confined to certain rather definite altitudes. The regional cloud masses, which accumulate moisture for the regional storms, normally occur between the elevations of 14,000 and 16,000 feet. At these levels, temperatures are very near freezing even in summer, and maximum wind velocities approach 30 miles an hour. Wind direction, while not constant, is generally from the west and northwest.

Below 14,000 feet, the winds are normally the vagrant breezes of the parks, blowing "every which way," usually for no obvious reason. It is in this zone—from the ground surface to 14,000 feet—that the local or valley storms occur.

Above 16,000 feet is the zone of "trade winds" which extends upward to at least 18,000 feet, and probably much farther. Clouds in this air stratum move rapidly from west to east, often at velocities exceeding 50 miles per hour, as determined by "clocking" cloud shadows. Several wind velocities of more than 150 miles an hour in this air stratum have been reported by aviators, who "left Denver for Salt Lake and landed for gas at Limon."

So far as can be determined, clouds having elevations of 17,000 feet or more have no effect on the weather of the mountain region and are not affected by it, but sail serenely across the sky from west to east without either gaining or losing moisture.

Cyclones and anticyclones tend to alter the levels of these air strata temporarily; cyclones causing a downward warping, anticyclones warping the strata upward.

Explanatory Hypothesis.—From field observations in the Colorado Rockies and from current theories of local atmospheric circulation, a rather plausible hypothesis, explaining all of the major features of the regional storms, may be built up. This hypothesis is here presented with full awareness that it

is based on incomplete information, and hence may be subject to some or much error.

Regional storms are convection phenomena, largely confined to a definite area by rising air currents along the walls of the basin of their origin, and depositing much of their precipitation in the same general area from which it was originally evaporated.

Prevailing winds tend to mass the clouds of a regional storm on the leeward side of the basin of their origin, and to carry some or much of the evaporated moisture away from the basin.

In times of normal barometric pressure, convection caused by surface heating in a park continues until the heat supply ceases, either because of the formation of a large cloud cover or of the setting of the sun. Heated air, moistened by evaporation, rises to a height where condensation takes place. This determines the bottom of the regional cloud stratum. The top of this cloud stratum seems to be determined by the bottom of the "trade wind" stratum. Any moist air rising into the "trade wind" stratum is rapidly carried away, in the direction of Kansas. Whenever the height of condensation is below the base of the "trade wind" stratum, a regional cloud layer may form. Between the base and top of a regional cloud stratum, the normal violent cumulus convection takes place.

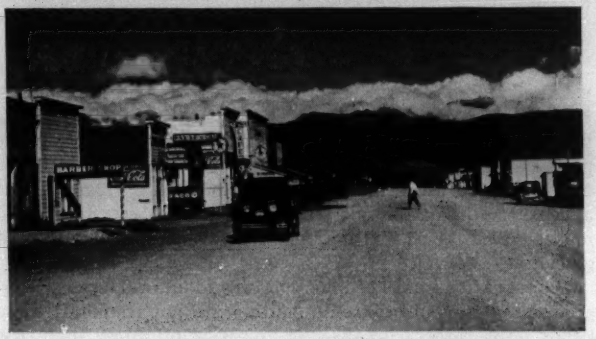
As the cloud cover over a park thickens, by gradual accretion of water vapor, it tends to reflect more and more of the sun's radiation back into space, barring it from access to the ground, and eventually greatly reducing local convection. This is accompanied by a general cooling of all the air from clouds to ground, and often precipitation of the moisture held suspended by the clouds.

Failure of the regional storm cycle to complete itself with a rainstorm during weather of normal barometric pressure is due to insufficient moisture, and almost invariable accompanies either drought or freezing in the parks.

Comparing field observations and theories still farther, abnormal conditions may be hypothecated, and compared with observed occurrences.

Abnormally low upper air temperatures, abnormally low barometric pressure, and abnormally large amounts of available moisture on the ground, all tend to lower the base of the regional cloud stratum to or below the rims of the park walls. These conditions inhibit west-east moisture migration by retaining the clouds in the parks. This leads to a very wet summer in the mountains, accompanied by drought on the high plains. The summer of 1936, when it rained for more than three hours on 80 of the 84 days spent in the field

FIG. 10.



CLOUDS IN EASTERN MIDDLE PARK DURING AN ANTICYCLONE.

Photographed from the main street of Granby, Colorado, near the junction of the Colorado and Fraser Rivers, these clouds, associated with the valley storms, but lifted several hundred feet above their normal elevations by a valley breeze, completely hide the Front Range (Fig. 1, number 10), although the top of the highest cloud is only about 12,000 feet above sea level, while the crest of the range here averages over 13,000 feet. At this time the typical regional cloud stratum was absent, due to an anticyclone over the mountain region.

(eastern Middle Park), is typical of a wet mountain summer. Dust storms on the plains attested to the drought there. This would suggest that the supposed inverse relation of mountain to plains rainfall is something more than mere rural "guesstimation."

During a wet mountain summer, most of the few glaciers now present in the high cirques gain a few thousand tons of ice, and many of the snowfields do not melt away as rapidly as usual. It would seem, from this, that a depression of the regional cloud stratum by only a few hundred feet, as now

occurs from time to time, would, if continued for a number of successive summers, bring about a minor ice age in the mountains, perhaps of as great a magnitude as the small post-latest-Wisconsin ice advance noted in this area.[11]

Abnormally warm upper air, abnormally high barometric pressure, and drought in the parks, tend to raise the level of the regional cloud stratum, or suppress it altogether, due to the mixing of rising air from the parks with the air of the "trade wind" stratum. These conditions assist west-east moisture migration, leading to extreme dessication of the parks, rapid melting of the mountain snowfields and glaciers, and make more moisture available for precipitation somewhere east of the mountains.

No extreme case of this has been observed, nor do the weather records or old timer's tales tell of such happenings. It seems probable that mild suppression of the regional storms has taken place during periods of abnormal rainfall on the plains, but that severe cases have not occurred since the coming of the white man to North America. Theoretically, at least, a summer of this kind would lead to extreme glacial melting, if not to the extinction of many of the small mountain glaciers.

Observations of the annual layers in Fair Glacier [12] suggest that periods of extreme melting are not frequent, there being only three "breaks" in a series of more than 400 annual ice bands. How many years are represented by these unconformities in the stratified ice has not been determined, and as another unconformity seems to be in the making at present, conclusions as to past climate, drawn from the ice band record, may be of little value. Glacial records do not reveal the speed of melting, but only that melting in excess of the annual accretion took place.

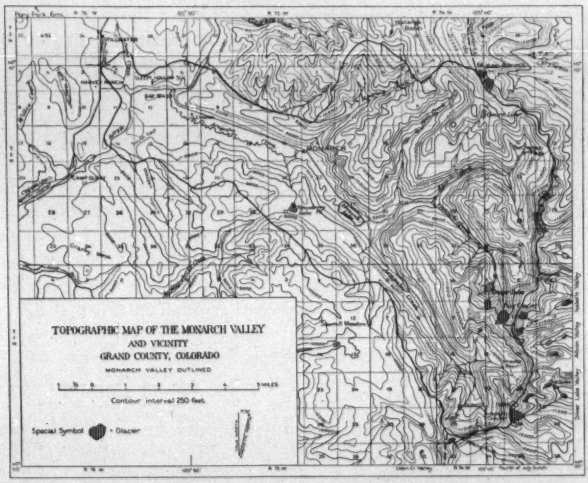
Valley Storms.

Valley storms, securing the major part of their moisture from the same valley into which they later precipitate it, and taking place wholly within that valley, are local phenomena which are repeated many times in the Colorado Rockies.

In this area, a maximum of four regional storms can take place at one time. No more are possible . . . there are only

four major parks. In contrast, there are more than 500 valleys in the Colorado Rockies that could, at least theoretically, contain simultaneous local storms, and probably more than 200 of these valleys actually do have a daily storm within their confines during part or all of the mountain summer.

FIG. 11.



MAP OF THE MONARCH VALLEY, GRAND COUNTY, COLORADO.

(Data from field notes and U. S. G. S. Rocky Mountain National Park Quadrangle.)

From the Colorado River to Monarch Lake are the "flats," once the melting basin of the Pleistocene glaciers that carved the valley. Above Monarch Lake, to about the 10,000 foot contour, are the tributary valleys, and from the 10,000 foot contour to the crest of the range are the cirques, in which are still present moribund remenental glaciers. Monarch Valley storms, in general, do not cross the watershed outline on this map except to the east, and in general, the top limit of valley storm disturbances is not more than 1,500 feet above the valley floor, except in the cirques, where vertical air currents carry storm clouds to a considerable height. The most rapid evaporation, in this valley, occurs in the "wet meadows" below the 8,250 foot contour. The most violent precipitation, from the valley storms, occurs above the 10,250 foot contour on both sides of the range, and below 13,000 feet.

These valley storms are distinct from the regional storms, taking place in a lower air stratum, and while largely caused by convection, they can take place when the regional storms are suppressed by an anticyclone, and do not, in general, interfere either with each other or with the regional storms,

except at the extreme heads of their valleys, during the period of maximum cloud turbulence.

More than fifty valleys containing storms of this type have been noted by the writer in various parts of Colorado, and in other parts of the state many more storm areas have been reported by skilled observers (mostly U. S. Geological Survey men). These storms are all quite similar in operation, and after a few days of observation, the actions of the storm in any typical valley can be predicted with a gratifying degree of success.

In the Monarch Valley, Grand County, Colorado, on the eastern edge of Middle Park (Figs. 1, 11), more than 100 of these storms were observed during the summers of 1932–1936 inclusive, and this valley will be taken as the type area, even though extended observations of local storms may show those of this area to be very slightly atypical.

Typical Valley Storm.—A typical valley storm begins shortly after sunup, with a rather rapid replacement of the early morning ground haze by a stratum of shimmering humid air that rapidly thickens until it fills the lower reaches of the valley from floor to rim. Any of this almost-saturated air that rises above the valley rim is immediately swept away by the park-wall convection currents associated with the regional storms.

Air currents begin to rise from the bottoms of the cirques at the heads of the various minor tributary valleys about half an hour after sunlight first reaches cirque floors, and shortly after noon, the entire valley system begins to "draw" like a chimney. Very humid warm air moves slowly up-valley (5–10 m.p.h.) from the flats to the cirques, markedly raising temperatures and humidities during the late morning and early afternoon. Valley air, during this time, is almost saturated. Sweat does not evaporate, moisture condenses on everything cool (particularly inside instruments and lens combinations) and the air is oppressive. During these mid-day hours, mountaineers often experience a rather acute exhaustion, a condition almost identical with "glacier lassitude," which may have a similar cause.

Cloud formation begins over the cirques in late morning with tenuous and ephemeral wisps that become larger and

more lasting as the day progresses. During the early afternoon, definite and somewhat lasting cumuli form over the cirques at elevations near 13,000 feet, and slowly drift eastward, rising slightly as they encounter cirque-wall "chimney currents." It should be definitely noted that these cumuli are in no visible way related to those of the regional storms that form more than 1,000 feet higher (Fig. 15).

FIG. 12.

THE MONARCH VALLEY IN MIDMORNING.

With the camera pointing southeast, this photograph was taken from the north lateral moraine (Fig. 11, sect. 8, T 2 N, R 75 W) of the glacier that excavated and formerly filled the valley. Although panchromatic film and a deep yellow filter were used, the mountains, fourteen miles from the camera, are partly obscured by evaporation haze. In the lower right are the "wet meadows" from which intense evaporation takes place, and into which the entire valley system drains. On the horizon are the regional storm clouds, and in the middle distance are the shadows of others. Mid-morning conditions on a "normal" day are here shown.

Over each cirque, in general, only one cumulus forms. The time of formation of the cumulus is slightly different for each cirque of a valley system, and the time of maximum cloudiness over adjacent valley systems is not necessarily the same, although maximum cloudiness is seldom reached earlier than noon, or later than five in the afternoon.

While the cumuli are forming over the cirques, definite air currents are established in the valleys. Those from the flats to the cirques follow paths a few hundred feet above the valley floors, and having about the same gradient (minor bumps and hollows in the valley floor have no detectable effect on the moving air). Those near the cirque headwalls are almost vertical. The transition from valley to "chimney" currents is very sharp, often taking place within a few hundred feet.

Just before the valley storm breaks, there is a very pronounced cooling of the valley air, and a downward extension of the cumuli into the cirques to within a few rods of the cirque floors. Violent air currents carry dust, twigs, leaves, and sometimes rock flakes from the valley floor and walls up into the cumulus. Whistling, hissing, and roaring sounds, caused by the rapid passage of the wind over sharp rocks, and a low-pitched "fluttering," accompany this phase of the storm.

Suddenly, all sounds stop. Usually the silence, which may last for a dozen seconds, is broken by a sharp thunderclap, and followed a few seconds later by a violent downpour. As the precipitation begins, the valley air currents rush toward the cirques, clouds materialize suddenly in the tributary valleys, and race upward toward the main cumulus in and over the cirque at the head of each tributary, increasing in size as they travel.

Cloud wraiths stream eastward through gaps in the range at the valley heads, reform into cumuli on the eastern slope, and, tossed violently about by the "chimney currents" spread rain and hail over a mile-wide zone parallel to the range crest. A few small cumuli may cross the range in favorable locations, but usually these are badly torn by uprushing air currents before they have travelled many rods beyond the range crest.

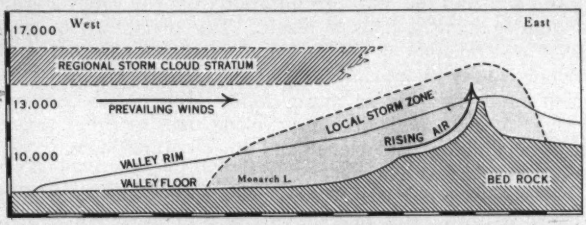
Hailstones, usually less than 3/4" in diameter, but occasionally as large as 2" (measured), are commonly precipitated from clouds of valley storms that have crossed a divide, but are seldom observed in precipitation from clouds still over the cirque in which they formed.

Clearing of the air after a valley storm is quite prompt, usually taking only thirty minutes or so, regardless of the

atmospheric conditions above 14,000 feet. Two rain-storms in the same afternoon, caused by the breaking of one type of storm after the clearing following another, are often noted in the valleys. When the valley storm breaks much before the regional storm, the valley air, in late afternoon, will clear, then later "fog up" as a result of regional storm precipitation. If, on the other hand, the regional storm breaks first, there will be violent rains and bright sunshine during the valley storm.

Valley storms in the Monarch Valley begin as early in the year as there is water in the "wet meadows," and continue to be an almost-daily occurrence until the "wet meadows" are

FIG. 13.



PROFILE OF THE MONARCH VALLEY.

Data for this figure were obtained from the U. S. Geological Survey map of the area (somewhat generalized), and from cloud observations. Vertical intervals are thousands of feet, horizontal intervals are miles. It should be noted that the local storm zone, roughly confined to the tributary valleys and cirques, extends upward into the regional storm cloud stratum near the cirques, causing, in this area, interference between storms whenever they are nearly or exactly simultaneous.

covered with ice, or the water available for evaporation from them is greatly lessened by drought. The season usually lasts about 160 days, during which time there are about 125 valley storms, not all of them severe. Other valleys, in different ranges, or having different exposures or potential water supplies, have seasons of greater or lesser length.

Effect of Cyclones and Anticyclones.—Cyclones have a definite, but not easily determinable effect on valley storms, as they tend to "telescope" the several condensation levels into one, making separation of storm components difficult or impossible. In general, the precipitation in a valley is less violent and more lasting during a cyclone, with smaller rain-

drops, less thunder and lightning, and practically no hail. This generalization falls down in the event that the cyclone brings a summer blizzard, when almost anything may be expected. With the coming of a cyclone to the mountain region, it seems more logical to lump the local and regional storms as a single local factor than to try to consider them, and their effect in the cyclone, separately.

Anticyclones, while suppressing regional storms, have a rather slight effect on the valley storms. During the first day of an anticyclone, the level of condensation of the valley air is raised, permitting the valley storm cumuli to drift across divides with less fragmentation. The evaporation in the wet meadows is somewhat greater, because of the warmer air and clearer sky, and the total precipitation from the valley storms is slightly increased, as a result. The precipitation on a given area remains about the same, whether or not an anticyclone is over the mountains, but the area rained on is very much greater during an anticyclone. Hail is less common during the first day of an anticyclone than at other times. After the first day, cloud levels and other features of the valley storms slowly revert to normal.

Topographic Factors.—Without the steep-walled glaciated valleys, it is doubtful whether this type of storm could take place in the Rocky Mountain region, for the existence of these storms seems to depend upon topographic features that are normally caused only by mountain glaciation. While no exact comparisons of valleys are possible because of the great topographic difference between them, valley systems having the steepest gradients, the most abrupt cirque walls, the largest melting basins, and the narrowest tributary valleys, seem to have the most violent storms. Rather strangely, while relatively straight valley trends should increase the velocity of the air currents, and hence the violence of the storms, there seems to be little or no difference between those in straight and crooked valleys, all other things being approximately equal.

The trend of the valley with reference to the prevailing winds seems to be an important factor governing the violence of the valley storms. Valleys on the windward side of a range, in general, have more regular and more violent storms

than those cut into leeward slopes. The prevailing winds seem to reenforce the rising air currents in windward-facing valleys, and to oppose those in leeward-facing valleys. Adequate shelter, such as a half-mile-high cliff, at the head of a leeward-facing valley seems to reduce the inhibitory effect of the prevailing winds on the valley storms.

Absence or small size of the melting basin of the glacier that cut and once occupied the valley, or better-than-average drainage of that basin, is a definite inhibitor of valley storms. Theoretically, a steep-walled melting basin should be less effective in storm production than one with more-gently-sloping walls, but as no observed melting basin has walls so steep that they cast a shadow on the wet meadows within it for any length of time, that factor is probably negligible.

The mathematical possibilities of these various relations are intriguing, and a series of very complicated and impressive-looking equations, that should explain everything, can be set up. Their only fault is that the answers, unless a "boogle factor" is somewhere inserted into the calculations, bear no relation to observed occurrences. It seems probable that present field data and theories are too qualitative to justify mathematical treatment of the problem.

Year-to-year Variations.—Variations in the intensity and timing of the valley storms from year to year have been noted both by the writer and by "old timers" in the mountains. In general, since 1934, the regularity of the storms has been somewhat disturbed, their precipitation has been largely concentrated on the western slopes, and more snow has accompanied them than was usual in the past. These conditions are similar to what would be expected if a mild cyclone settled over the mountain region.

From a time before the coming of the oldest now-living mountain residents until 1934, storms in many valleys occurred with such regularity that they were named the "two o'clock rains," or given some similar title suggestive of clock-like regularity. Probably these storms have been disturbed, in the last few years, by the same occurrences that have upset the timing of the regional storms; probably a slight chilling of the upper atmosphere. Whether or not they will resume their regular periodicity in a few years remains to

FIG. 14.

VALLEY STORM CLOUDS RISING IN A CIRQUE.

This photograph was taken from the summit ridge of Lone Eagle Peak (ca. 12,600′) in the Crater Lake Hellhole, between Crater Lake and Fair Glacier (Fig. 11) in midafternoon. The rising air currents here, a part of the cumulus convection, were quite violent, and "fluttered" audibly as they blew past the sharp edges of the rocks. This area, one of the cirques at the head of Cascade Canyon, has a rainfall estimated (from precipitation area and outflow) at nearly 100 inches during the summer. Parts of the valley only a mile downstream receive less than one quarter as much. In eleven visits to Crater Lake, each lasting 24 hours or more, only four hours of "good photographic weather" were experienced.

be seen. So far as can be determined, there is no simple relation between sunspot cycles, or other natural rhythms, and this disturbance of the valley storms.

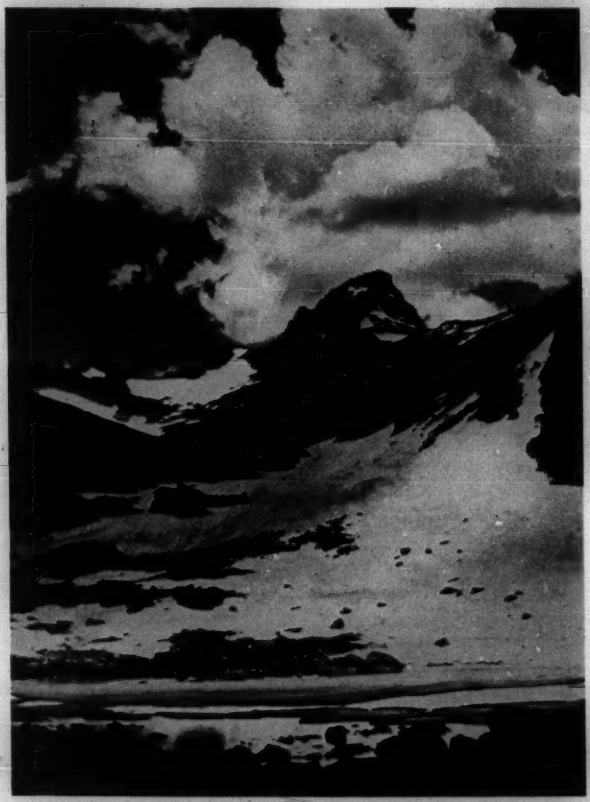
Variations in a Single Season.—Like the regional storms, the valley storms tend to decrease in intensity simultaneously with the observed late summer decrease in insolation and water supply. Less heat and less water decrease possible evaporation, and hence considerably lessen potential precipitation from clouds of local origin. The relative decline in rainfall from the valley storms is greater than that of either insolation or moisture available for evaporation. Unlike the regional storms, the valley storms seldom die out altogether until the melting basins, their source of moisture, are either completely dry or frozen over. Except in the San Luis Valley, complete dessication of a melting basin is exceptional, even when the parks suffer from very severe drought.

In various parts of Colorado, the valley storms begin to decline in intensity at different times, as might be expected from differences in initial water supply, drainage, and climate. Storms in valleys tributary to the San Luis Valley decline in intensity and sometimes die out altogether before the end of June. In a few valleys in the southwestern San Juan Mountains (Fig. 1, number 17) the storms cease from lack of moisture in mid-July. A marked decline in the precipitation from the storms in any valley may be expected soon after the snowfields in the cirques have melted away, and a further decline or complete cessation should follow some weeks later, when the melting basin dries up. However, the time from the vanishment of the snowfields until the first good freeze is usually too short to permit complete drying of the wet meadows in the melting basin.

Barometric Effects.—It is not possible, from available data, to definitely differentiate between the barometric components of the valley and regional storms. The two together, however, have a very definite effect on barometers in the mountains, and introduce easily recognizable bumps and hollows into the barograph traces of stations on the plains near the mountains.

It was originally planned to separate these components by comparisons of plains station barograph traces. Those varia-

FIG. 15.



CUMULUS HANGING OVER A CIRQUE.

This cumulus has its origin in and over the Crater Lake Cirque (Fig. 11), and is hanging between 13,000 and 14,500 feet. Shortly after this picture was taken, the cloud drifted eastward, enshrouding Navajo Peak, on the horizon in this picture, and traveled over the Albion and Isabelle Valleys, spreading rain and hail over several square miles on the eastern flank of the Front Range (see also Fig. 16). Foreground shadows are those of clouds drifting across the range from Wheeler Basin.

tions occurring on days when no cyclones or anticyclones were over the mountain region should be of mountain origin, and changes shown only on one or two traces should be of extremely local, and hence of valley storm, origin. A number of such comparisons were made, and the results found absolutely inconclusive. It seems probable that an additional trace, from a plains station far from the mountains, is needed, so that components of purely plains origin can be eliminated before search for mountain components is begun.

In general, a violent regional storm, or group of them, produces a characteristic "battered sine wave" barograph trace over wide areas (Fig. 9). Milder regional storms may or may not produce easily recognizable bumps and hollows in plains barograph traces.

Close to the mountains (in Boulder, for example), each nearby valley storm produces its own definite "dip" in the barograph trace, causing a steplike declining trace on many summer afternoons (Fig. 17).

It is often possible to go out to a point on the plains about 30 miles from the crest of the range and watch the storms, then wait a few minutes and observe the "dipping" of the barometer that in the mountains should theoretically accompany the breaking of the storms. From rough calculations, it appears that barometric disturbances accompanying regional and local storms of normal intensity may travel as far as 150 miles from the mountains, at velocities as high as 80 miles an hour.

Attenuation of these disturbances is rapid, and they may be completely masked, at a point some distance from the mountains, by purely local barometric disturbances.

In the mountains, an aneroid tends to read rather consistently from sunset until 10 A.M. The drift, at 9,000 feet, on an instrument calibrated in feet, is about 30 feet per hour; downward (indicating lower elevation) until about two A.M., then upward (higher elevation, lower pressure) for an hour or so, then downward again until midmorning. From midmorning until just before sunset, the needle "jitters" violently, and altitude measurements made with an aneroid during this time are correct within 500 feet only by chance. During midafternoon, from the time of formation of the

densest cumuli of the regional and valley storms until the sky clears shortly before sunset, altitude readings at 14,000 feet may be as much as 3,000 feet off, plus or minus, and two readings in the same location, taken at intervals of one minute, may differ by 1,000 feet.

FIG. 16.

VALLEY STORM CLOUDS STREAMING THROUGH GAPS IN THE CONTINENTAL DIVIDE.

This normal midafternoon phenomenon was photographed from the summit of Navajo Peak (Fig. 15), the view including the cirque at the head of the Albion Valley (Fig. 11) and Wheeler Basin (through the gap). These clouds originated in Wheeler Basin and the Crater Lake Hellhole, and after "worming their way" through gaps in the divide, they reformed, at about 12,000 feet, into cumuli which were soon tossed upward by air currents of plains origin, and later precipitated rain and hail onto the east flank of the Front Range near the divide.

A very heavily damped instrument, such as a mercurial barometer, indicates a pronounced afternoon "low" over the mountains while regional and local storms are forming. In this connection it is interesting to note that many of the major Colorado peaks, now known to be less than 14,500 feet high, were assigned altitudes of more than 17,000 feet by the pioneer surveyors, who determined elevations from the temperature of boiling water. The very fact that these altitudes

are 3,000 feet too high proves that the determinations were honestly and accurately made.

Precipitation and Moisture Transfer.—Precipitation from the valley and regional storms cannot, in general, be differentiated. Total precipitation varies from something more than one inch per stormy day in certain small areas within cirques to about one-tenth of an inch per stormy day in the centers of the parks. This, it should be remembered, is the rain that reaches the ground, *not* the total precipitation from the clouds.

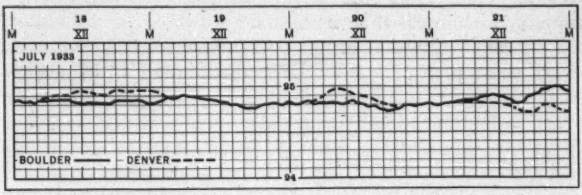
As most of the rain over the parks and valleys is part of a "closed circuit system" it is of little real importance outside of the particular valley or park, contributing little or nothing to the runoff from the area, and being reevaporated, in general, within less than 24 hours.

The small fraction of the total precipitation that "spills over" the topographic boundaries of the place of its moisture origin, however, is of great climatic importance. The "spill-over" amounts to about 1/10 of an inch of water per stormy day on an area about a mile wide just east of the crest of each major mountain range. As there are about 100 days during an average year when either valley or regional storms, or both, take place, this results in a west-east transfer of about 550 acre-feet of water for each linear mile of range, or an eventual transfer of about 130,000 acre-feet of water from the Colorado to the Mississippi drainage, little of which is recorded by the rain gauges of the weather stations! This is about 1/25 of a cubic mile of water. A very small amount of moisture is also transferred from the Colorado to the Rio Grande drainage. These figures, which do not include the very violent rains and occasional snows brought to the high country by cyclones, are based on admittedly crude measurements, and are probably minima, rather than averages.

Explanatory Hypothesis.—Valley storms, like the regional storms, seem quite definitely to be "closed circuit" convectional phenomena. They differ from the regional storms in that the circuit is shorter, and less affected by outside influences, such as cyclones, anticyclones, and regional droughts.

From field observations, it seems that these storms vary in violence with variations in available energy (effective insolation), available water, air circulation, and the topographic factors already described. During the first part of the summer, daily loss from "escaped" moisture seems to be more than replaced by water freed by the melting of snowfields at the valley heads. The excess water runs off, and increases that available in the park into which the valley drains. As the water level in the wet meadows, occupying much of the melting basin remains relatively constant for much of the valley storm season, the water available for evaporation in the valley is quite constant. The intensity

FIG. 17.



COMPARATIVE BAROGRAPH TRACES, DENVER AND BOULDER, JULY 18–21, 1933.
(Data from U. S. Weather Bureau and the University of Colorado.)

These traces are of a normal interval, when "outside" influences were small, and the mountain storms, both regional and valley, were behaving in the "traditional" manner. Note the "steps leading down" in the Boulder trace each afternoon, caused by the sequent breaking of the valley storms on the eastern edge of Middle Park (Fig. 1), and the similar steps in the Denver trace, which are not so sharply defined, as Denver is farther from the mountains. The trace of the 20th is characteristic of those produced by an extra-violent regional storm over South Park.

of a given valley storm, then, seems dependent on three variable factors—effective insolation, air circulation, and the atmospheric thermal gradient. As these three normally vary only within quite narrow limits, the usual regular periodicity of the valley storms is not surprising.

The daily cycle in a valley storm area begins with rapid heating and humidification of the air over the moisture source, usually the wet meadows in a glacial melting basin. It seems probable that from these wet meadows there is more evaporation per acre, early in the morning, than is possible from a similar area of lake surface, for the total area from which evaporation can occur in a vegetation-covered meadow

is far greater than the acreage, and each blade of grass, early in the morning, is covered with dew. As a result of this heating and evaporation, a large volume of buoyant, warm, moist air is present in the lower part of a valley, and, expanding, seeks the easiest outlet. Major relief is limited by topography to three directions—vertically upward, upvalley, and downvalley. Minor relief is possible along the valley walls, but no important air currents have been observed along valley walls below the cirques, probably because of their steepness.

Downvalley relief of pressure seldom takes place, for both the buoyancy of the air, and the masses of cooler, denser air downvalley oppose such motion. Often, the only outlet from a melting basin is a narrow canyon, sufficiently large to carry several times the present runoff from the valley, but too small to permit rapid motion of large quantities of air in either direction.

Vertically above the melting basins, relief undoubtedly takes place, and some of the heated moist air is diluted and carried upward by the regional storm convections. The currents rising along the walls of the larger topographic basins, into which many of the glaciated valleys drain, tend to give an upvalley motion to any air coming into contact with them from below. Currents from the plains have an almost identical effect.

The prevailing winds, acting from the west, give a slight upvalley motion to air in the windward-facing valleys, and also strengthen the park-wall convections over them. In the lower parts of leeward-facing valleys, the effect of the prevailing winds seems to be minor and inhibitory.

As a result of the actions of these various forces, there is, in the region of the melting basins, in midmorning, an unstable mass of warm moist air, with a strong tendency to move upvalley, at a gradient somewhat steeper than that of the valley floor.

While the melting-basin air is being heated and humidified, the air of the high cirques is being heated, giving it a tendency to rise. Convections of small magnitude are set up in the cirques, leading to the formation of the ephemeral morning

cloud wisps above them. By midmorning, the cirque air is unstable, and tends to rise vertically.

Air in the tributary valleys begins to heat as soon as sunlight reaches the valley floors, and likewise becomes buoyant and unstable. Given a slight upvalley motion by the prevailing winds and the park-wall convections, and pushed by the melting-basin air below it, the air that spent the night in the tributary valleys moves upward into the cirques, forcing the cirque air upward, and is replaced by warmer, wetter melting-basin air.

This shifting of air takes some time, but it is the beginning of the afternoon "chimney" circulation. Formation of the lasting cumuli over the cirques logically takes place as soon as some of the very moist melting-basin air rises into the air strata over the cirques, and continues until precipitation takes place, or the "chimney" currents cease, because of decreasing insolation, very late in the day.

Rain falling into the valley system from which it originated returns to the wet meadows during the night, and some of it is again evaporated the next day. The entire water circuit, except for the small amount of moisture that "escapes" over divides, is quite definite and easily observable. The return path of the air which rises in the "chimney currents," however, is not surely known. A small amount of cool dry air drifts down the intervalley divides, which usually have a rather flat upper surface, but this return, by the most generous estimates, accounts for only about one per cent. of the air that is carried upward by the valley storms.

Other Phenomena.

Numerous picturesque, interesting, or terrifying minor phenomena are reported by mountaineers and visitors to the mountains, and some of these have been observed often enough to permit fairly accurate descriptions and partial analysis of the forces involved.

Cloud Plumes.—Among the picturesque sights on many summer days are the great cloud plumes that stream eastward, sometimes for miles, from the high peaks. These are best developed about those major peaks that are several miles east of the range crest, such as Longs Peak and Mt. Evans

FIG. 18.

ENORMOUS CLOUD PLUME RISING FROM THE LONGS PEAK GROUP.

Large volumes of very warm, nearly saturated air, rising from three great cirques cut into the flanks of Longs Peak, and coming suddenly into contact with the very cold rapidly-moving summit winds at about 14,000 feet, cause this plume, which extends more than ten miles east of its source. Plumes of this great extent are not common.

The greatest of these plumes seem to be valley storms whose normal course was upset by the effects of violent cold summit winds east of the main Front Range (Fig. 18). When the summit winds near Longs Peak are especially cold, the valleys below the peaks abnormally warm, and the water supply in those valleys adequate, giant plumes of this type may be expected. These conditions occur only a few times a year.

Warmed and nearly saturated air, from the melting basins of extinct glaciers in the leeward-facing valleys, rises upward in a number of cirques cut into the sheltering flanks of these great peaks, and suddenly comes into contact with the bitter-cold, rapidly-moving summit winds. Immediate cloud formation takes place, and the resultant cumuli are carried some miles by the wind before they finally dissipate.

Were it not for the violence of the summit winds on those rare occasions when air from the leeward valleys carries its moisture as high as 14,000 feet, precipitation would take place within a few hundred feet of the zone of contact between the valley air and the summit winds, and the moisture would flow back to the melting basins. This would be a normal valley storm.

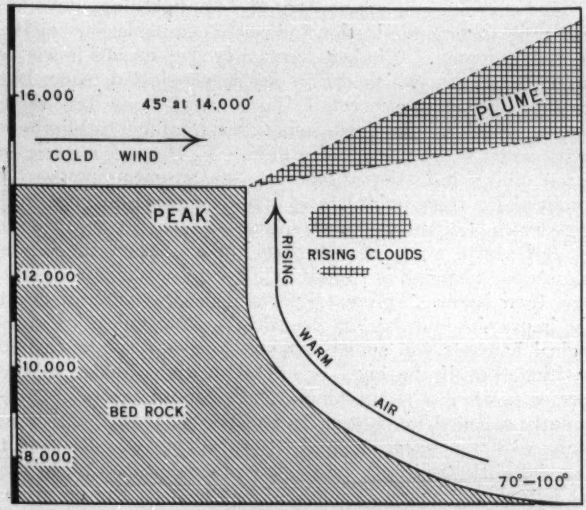
Cloud plumes formed where moist air from one cirque comes into contact with normally-cool summit winds are quite common, resemble the banner cloud described by Humphreys,[13] and have a length seldom exceeding one mile. These appear to be normal recurrent phenomena when not suppressed by the valley storms, and are frequently noted, at all seasons, to leeward of many of the higher peaks.

These plumes are used as weather indicators by residents of the mountain region: a rather flat-lying plume indicating high winds in the mountains, a dense plume warning of very cold weather "on top," a nearly vertical plume telling of mild winds in the high country, and no plume suggesting warm air on the summits. This use seems to be justified, the predicted high country weather agreeing quite closely with what is later encountered. A schematic diagram, showing factors in the formation of a normal plume, securing its moisture from a single cirque, and not complicated by the presence of valley storm clouds, is shown in Fig. 19.

Electrical Effects.—Numerous electrical effects have been reported from various locations in the high country, and some of these have been repeatedly observed.

Direct strokes of lightning are common at high altitudes, particularly in certain rather limited areas, which are locally

FIG. 19.



CLOUD PLUME FORMATION.

Leeward of a high peak, where glaciation has oversteepened the slopes, warm moist air from the valley rises in the sheltered cirque, forming ephemeral cloud wisps as the air cools, and dense plumes of cloud when the updrafts meet the cold and rapidly-moving summit winds. At some distance from the peak, the plume widens and finally dissipates as it mixes with the cold dry air of the summit winds. Conditions here shown are those in the Chasm of Longs Peak, near Estes Park, Colorado.

reputed to "draw" lightning. Quandary Peak, in the Mosquito Range (Fig. 1, number 11), is one of these. Investigation shows that direct strokes of lightning to this summit are extremely numerous, and that the probable cause is a dike of black, somewhat magnetic material that runs vertically through the peak, and forms the summit ridge. In some of

the other repeatedly-struck areas, the probable cause is not so easily determined.

Cairns on the higher peaks are frequently demolished by lightning, and trees near timberline are sometimes blasted into small chips by direct strokes. Lightning causes about two deaths annually in the mountains, humans being unable to survive a direct stroke.

Induced charges, a secondary effect of lightning, make life miserable for communication and power companies serving the mountain region. Climbers frequently are knocked down by induced charges, which do no severe physical damage, but cause rather severe nervous shock which may last some hours. Milder inductions sometimes produce pseudorheumatic pains, which pass in a few minutes. Hats are sometimes lifted off by induction discharges, and women are greatly annoyed by their hair, which literally stands on end until the electrical disturbances are over.

A favorite stunt of mountain guides, when the air is thoroughly charged, is to imitate Thor by waving an ice-axe over their heads. The metal parts of the ice-axe draw down an impressive display of electrical pyrotechnics. A geological hammer will sometimes spit long hot sparks in one position, but if the head is turned at right angles to the former position, the sparking stops. Mountaineers are frequently alarmed by the sparks emitted by their metal hobnails, with the resulting mild shocks. They usually detect charged air by raising a finger above their heads. When the air is heavily charged, sparks will sizzle from the fingertip, making a noise like frying bacon.

Induced electrical discharges frequently demagnetize or reverse compasses, and ruin photographic films by discharging inside cameras or film holders. Occasionally watches and aneroid barometers need readjusting after being carried through violent high-altitude electrical storms.

Ball lightning is occasionally reported by climbers, and many of the reports are undoubtedly genuine—that is, the climber honestly believes he saw just what he reports. It is interesting to note, in this connection, that a luminous visual image, that seemingly travels quite a distance, finally changing color and dying out, can be produced by firing a photoflash

bulb without warning somewhere near the outer limit of a "victim's" field of vision. He will report that a greenish or reddish ball wandered into his visual field ("traveled along the wall in front of me"), became smaller and changed color near its center ("right in front of me"), then vanished suddenly. The subject should not know in advance what is going to happen, and no two people will give identical reports of their sensations when this experiment is tried. From this, and the lack of a more satisfactory explanation, it is suggested that ball lightning is an optical illusion, caused by a very brilliant lightning discharge somewhere near the limits of the observer's visual field.

Coronas, halos, and standing arcs have several times been observed by the writer when spending the night at very high altitudes (above 12,000 feet). These phenomena, never twice the same, sometimes attain considerable brilliance, and seemingly have their source in some insulated conducting metal object.

Coronas, as the term is here used, are luminous discharges originating on the surface of an object and extending outward for some distance (sometimes several feet). They are usually red or reddish-purple, although a brilliant green corona has been seen twice; and roughly resemble in outline the object from which they extend. Often, when coronas are present, a person will apparently be bathed in flames, although he himself will be unaware of it. At times, the source of a corona will give very severe electric shocks when touched, at other times it seems electrically "dead" and may be contacted with impunity.

Halos are probably special cases of coronas, having the same colors and form, but between the halo and the haloed object there is a well-defined nonluminous zone. Both halos and coronas tend to be more brilliant in one vertical plane than another, so that a halo around a person may be more easily visible in profile than in "full face." This plane of maximum brilliance varies in direction from place to place, and may not have the same bearing for two successive minutes.

On several occasions, standing arcs, which could be drawn out from a conducting object, such as the head of an ice-axe,

or someone's nose, and then would continue to flare for some time, were noted. These exactly resembled the standing arcs produced from high-frequency equipment, and caused minor burns identical in appearance and slowness of healing with the "high frequency burns" suffered by radio experimenters. Exactly how a high-frequency discharge can occur in nature is not clear to the writer, and no explanation is offered for these standing arcs.

Attempts to measure the directional properties of high altitude electrical phenomena, using two ten foot lengths of wire and a small neon bulb, were not wholly successful. While every minor effect had a definite maximum strength in some azimuth, there seemed to be no definite relation between this and either the earth's magnetic field or the topography. With stronger manifestations, the results were even less informative, the neon bulb usually flaring with extreme brilliance for a moment and then exploding. Because of the great difficulty of getting neon bulbs in the mountains, and the very severe shocks suffered when handling wire on high peaks during static storms, these experiments were carried no further.

Somewhat similar electrical phenomena have been reported from the cosmic ray laboratory [14] on Mt. Evans (14,000+ feet, in the Front Range, near Denver), which seems to be abnormally prone to static storms and lightning discharges of unusual violence.

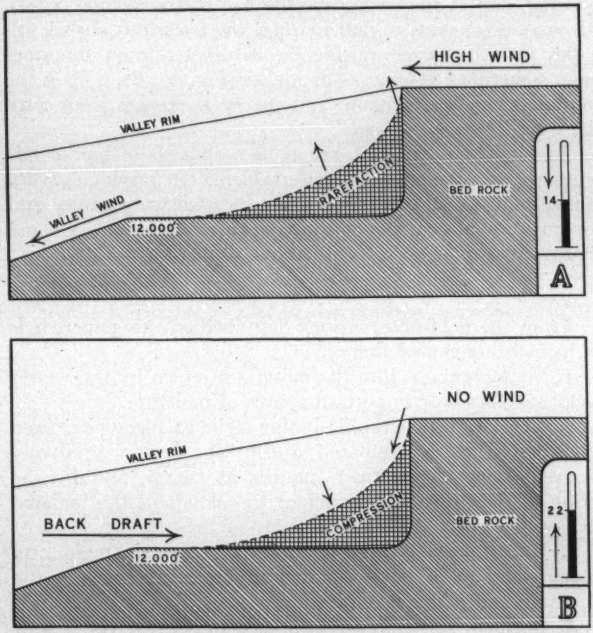
Backdrafts.—Many leeward-facing valleys near the mountain summits are noted for their violent reversing winds, locally called backdrafts, which seem to be caused by the blowing of abnormally-strong summit winds across deep, steep-walled cirques.

A number of these backdrafts have been observed from the cirques at the heads of the valleys in which they occur, and barometric and wind observations made during the worst of the atmospheric disturbances.

Most of these winds occur in cirques cut into the eastern flanks of high peaks some distance east of the main ranges, and receiving, in consequence of their location, more violent wind than peaks closer to or integral parts of the ranges. Cirque floors are usually about 12,000 feet above sea level, the cirque headwalls rising about 2,000 feet higher.

During a windstorm of this type, a barometer in the cirque will slowly drop to about 14 inches, as the wind,

FIG. 20.



CONDITIONS PRODUCING BACKDRAFTS.

For some minutes, winds blow across high cirques, sucking out the air, aspirator-fashion, and depressing the barometer far below its normal reading. This condition is shown in *A*, the arrows indicating directions of motion, not the forces at work. After an appreciable time, the summit wind ceases, and the backdraft rushes into the cirque, overfilling it with air, and raising the barometric pressure far above normal for the altitude. This condition lasts for only part of a minute, and is shown in *B*. The type location for these drafts is Summit Lake, on Mt. Evans, in the Front Range, west of Denver. Figure inserts represent the extreme barometric reading for conditions shown in the main figures.

blowing over the cirque, slowly sucks the air out of it, aspirator-fashion. The summit wind, during the barometric decline, is extremely violent; the downvalley wind, probably

induced by the summit wind, is more mild, seldom moving faster than about 30 m.p.h. (Fig. 20, *A*).

Suddenly, after some minutes of dropping barometer, the summit wind in the immediate vicinity of the cirque stops blowing, and at the same time the barometric decline ceases. After a few seconds of dull roaring, the backdraft rushes up-valley into the cirque, raising the barometer to an abnormal high, sometimes as great as 22 inches (Fig. 20, *B*). Then the summit wind begins again, and the cycle repeats itself until the wind "blows itself out."

As might be expected, the sudden changes of barometric pressure are extremely uncomfortable, often producing very violent nausea and internal pains, headaches, vertigo, and copious nosebleeds ("mountain sickness"), even in those thoroughly accustomed to life above timberline.

CONCLUSIONS.

From the field observations described in this paper, it is tentatively concluded that:

1. Snow, brought into the mountain region by the winter cyclones, is its only important source of moisture.

2. The large topographic basins serve as reservoirs, from which moisture accumulated during the winter gradually escapes during the warmer months as runoff, and by the action of the prevailing winds on the clouds of the regional and local storms.

3. Under present conditions in the mountain region, an inverse relation of unknown magnitude exists between the mountain and plains precipitation.

4. Regional and valley storms tend to increase the flow of the Platte and Arkansas Rivers, at the expense of the Colorado.

5. Elevation of the level of condensation of park-moistened air into the "trade wind" stratum, such as might be caused by a slight general warming or a decrease in available moisture in the parks, would lead to a suppression of the regional storms, a rapid melting of winter snows, and eventually to violent spring floods and late summer drought in the parks and on the high plains.

6. Depression of the level of condensation of park-moistened air, such as might be caused by an increase in snowfall, or a slight general cooling, would tend to confine park moisture wholly within the parks, resulting in an accumulation of snow in the high cirques, leading perhaps to a minor ice age, and increasing the flow of the Colorado River, while decreasing the water supplies from the mountains to the Platte and Arkansas Rivers. A slight increase in the flow of the Rio Grande might be expected.

This would immediately cause drought on the high plains, but it seems probable that storms similar to the regional storms would soon be established along the mountain front, and that the final result, after some or many years, would be a milder, moister, high plains summer.

A lasting general cooling would also cause a southward migration of the cyclone tracks, augmenting the moisture available to the plains during the summer, and would inhibit evaporation and the spring melts, preserving more of the winter snow until late in the season.

7. Local or valley storms, because of the peculiar conditions causing them, would be affected less by climatic changes than the regional storms. The violence of the valley storms bears a somewhat direct relation to the heat supply to the source of moisture, all other things being equal, and hence, more violent valley storms should conceivably result from a slight warming, while their intensity should decrease with a slight general cooling.

General changes in temperature would very definitely change the length of the valley storm season. They would begin earlier in the year if the temperature were warmer, and would stop earlier in valleys having little snow storage in the high cirques, but would continue until later in the year, because of postponed freezing of the wet meadows, in those valleys having adequate snow storage in sheltered locations.

A decrease in general temperatures would delay the initiation of the valley storms and accelerate their cessation because of earlier freezing of the moisture sources. Some variation in the trans-range cloud drift resulting from these storms should be expected as a result of general temperature

changes, but just what that change would be is hard to predict until more quantitative data are available.

8. Daily afternoon cloudiness over the mountain region is a normal condition, leading to possible rain over the parks and to probable rain over the heads of the major valleys. Absence of the regional cloud stratum, and rain from it, can be expected when an anticyclone arrives over the mountain region.

In drawing these conclusions, it is fully realized that both the observational and theoretical data used are far from complete, and that revisions will probably be necessary when more adequate information, both field and laboratory, is available.

A number of additional weather stations, located in the various parks, and atop the more important ranges, would greatly expedite the gathering of the vast amount of observational data so badly needed to extend our knowledge of mountain weather. Until these data are gathered, and their significance learned, mountain residents, and those dependent upon accurate knowledge of mountain weather conditions, particularly available moisture, for their economic or physical existence, will suffer from the absence of adequate prediction facilities and methods.

POSSIBLE APPLICATIONS.

Further research into the problem of mountain weather, its prediction, trend, and possible significance, may lead to great increases in our knowledge in several fields more or less dependent upon knowledge of weather conditions and trends. Three of these fields—geology, irrigation, and aviation—will be briefly mentioned here.

Geology.—Many geologic processes are so directly influenced by weather conditions that a very slight change in the weather, continued over several or many seasons, will cause a considerable change in the process. Weathering, erosion, sedimentation and glaciation are the most important of these. In the mountain region, for example, some rock surfaces are alternately wetted and dried, others are continually wet, and still others are dry for days or weeks at a time. Minor shiftings of the local or regional storms, or

changes in their intensity, may change the mode of rock disintegration in a given area from one of leaching and frost-cracking to one of arid exfoliation with almost no accompanying chemical changes.

Erosion, being a function of the velocity of the eroding waters, rather than of annual rainfall, would likewise be greatly influenced by slight climatic changes—an increase in the violence of rainfall, even though the total annual rainfall might remain the same, might cause a great increase in total annual erosion. It is interesting to note, in this connection, that the basin range deserts of northern Mexico, having the least rainfall of any region in North America, also have the most rapid erosion, chiefly because the total annual precipitation occurs in a very few storms of extreme violence.

The products of weathering and erosion are eventually deposited as sediments, and from these it is sometimes possible to determine the conditions accompanying erosion or sedimentation, or both. From these, some idea of the climate during the time of sedimentation may be gained.

With the various storm types in the present Rocky Mountain region, there might, conceivably, be deposited a number of different sediments, in daily (throughout the summer), yearly, and perhaps other, layers. Varves, resulting from glacial melting and deposition of outwash in lakes, have been noted in many regions.

In previous studies of sediments, recurrent layers have almost invariably been classified as annual. Future work, in the enclosed basins of the Rocky Mountains at least, should take into consideration the possibility of a multiplicity of layers deposited during a single year. Annual varves, with daily subvarves in the unoxidized section, are at least theoretically possible in lakes receiving their inflow from valleys having a daily summer storm cycle.

Studies of existing and former glaciers in the Rocky Mountains must take recent and ancient climate into consideration. Today's glaciers, seemingly in slow retreat, are an important factor in the regulation of the flow of many streams, and in the maintenance of the regional and local storms. Their present situation seems precarious, a slight increase in net precipitation (more snow or less melting)

appears necessary if the glaciers are to last much longer. A very slight decline in net precipitation (less snow or more melting) would cause their rapid vanishment.

It is interesting to note that in the valleys having the heaviest rainfall today, the glaciers at their maximum extension were longest, suggesting that the areal distribution of precipitation has been about the same since at least mid-Pleistocene.

Irrigation.—Artificial redistribution of stream flow, as an aid to agriculture, has become of major importance in the flatlands adjacent to the mountains. The major part of the water used is runoff from the mountains, and not precipitation on the plains. Were it not for this water from the mountains, the plains would be a desert, unfit even for grazing. Disregarding all economic considerations, the supply of irrigation water is still strictly limited. No amount of prayer, money, or legislation will increase the average annual precipitation on the mountain region. All that can be done is to redistribute the present runoff from nonarable lands to those suited for cultivation.

Recently, a number of transmountain diversion projects have been proposed, the object being to remove water from the Colorado River drainage and supply it to the Platte Valley. In view of the apparent inverse relation of mountain to plains rainfall, the value of these projects as compensatory works, to maintain a constant average water supply in the Platte Valley, is hardly to be doubted, provided the diversion does not eventually upset the storm cycles in the basins from which the water is taken.

As potential evaporation from much of the irrigated region far exceeds the amount of water available, it seems probable that much irrigation water is wasted, being evaporated in the fields and carried great distances east by the winds to regions that don't need it. This quite definitely produces climatic changes, of unknown, but probably very minor, magnitude. Increased transmountain diversion, and expansion of the irrigated areas, may very well produce serious desiccation of the lower Colorado Valley, causing climatic changes of appreciable magnitude in adjacent areas. Owens Valley, California, is an example of a region desiccated by diversion

of its inflow. Once there was steamboat service on Owens Lake. Today the lake basin can be crossed by automobile. Unless extreme care is exercised, other areas may suffer a similar fate.

Aviation.—In the past, the Rocky Mountains were a barrier to covered wagon travel, then to railroad construction, and today they are a definite menace to aircraft, particularly to those carrying passengers and mail across the mountains on a more or less definite schedule.

Pilots today can determine their courses and locations with some certainty by the use of radio beams, but their altitude is still determined by an aneroid altimeter, which is reasonably truthful only in times of clear weather—just when it is least needed!

It is true that by climbing until the altimeter reads 17,000+ feet all danger of crashing into a mountainside may be avoided, even in the stormiest mountain weather, but this is hard on the pilots, reduces the pay load of the planes, and may have serious consequences for the passengers, who have, in general, little tolerance for either high altitude or rapid altitude change. (These figures are for the Colorado-Wyoming-Utah-Idaho region, where no peaks are over 14,500 feet high, and no altitude of much more than 17,000 feet has been recorded by the use of a barometric altimeter on a high peak.)

Pending the development of an "absolute altimeter," which will tell instantaneously the distance between a plane and the ground, it seems probable that air travel can best be expedited and made safer by a careful study of barometric conditions in the mountains along the regular course, and the installation of several radio-equipped weather stations in the areas of greatest barometric disturbance. These stations can broadcast information to planes at short intervals, warning against potential inaccurate altimeter indications, and supplying local corrections to nearby planes when needed.

This should be an improvement over the present practice of using an altimeter corrected for pressure at a landing field on one side of a range while flying over a region whose weather may bear no relation to that for which the altimeter is adjusted.

ACKNOWLEDGMENTS.

A complete list of those who have given assistance in the collection of these data, and in the preparation of this paper, would fill several pages of fine print, and would include people in such varying social and intellectual strata as an illiterate Indian sheepherder and a former head of the U. S. Weather Bureau. To the large number of ranchers, miners, linemen, small-town telephone operators and rural mail carriers who assisted in the gathering and checking of information, the writer expresses his appreciation.

Special mention is due Dr. and Mrs. Chas. E. Snow, of Lakewood, Colo., for assistance in the field; the Greenman Stores Co., of Boulder, Colorado, for securing special items of equipment and for storing infra-red films in their refrigerator on several occasions; Mr. Chas. F. Snow, of Boulder, Colo., for advice and assistance with difficult photographic problems, and the Colorado Mountain Club for access to numerous records and photographs.

The writer is especially indebted to the U. S. Weather Bureau for information; to the University of Colorado for the use of numerous barograph and thermograph traces; to various members of the U. S. Geological Survey for reports of weather conditions in the mountains, and to Drs. W. J. Humphreys and A. H. Thiessen for valuable discussions of the phenomena encountered in the field.

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New Industrial Uses for Farm Crops.—DR. H. E. BARNARD. (*Refrigerating Engineering*, Vol. 36, No. 3.) In his paper presented at the meeting of the A.S.R.E., Dr. Barnard, of the National Farm Chemurgic Council, stated that to the chemical engineer the farmer is essentially a manufacturer, for he produces materials that, in the not so distant future, will provide not only a practical and permanent cure of the farm problem but by means of proper processing will give to the consumer new and better goods. Already the program is under way, as is evident from viewing a number of industries. The plastic industry is one of the fastest growing of the chemical industries. It uses a great variety of raw materials produced on the farm, casein and soybeans, cotton or wood pulp and acetic acid which form cellulose acetate, and glycerine, a byproduct of the soap or oils and fats industries, which is the basic material in the new Glyptol resins. Starch from the sweet potato is another example. Cornstarch is a basic material essential in a great number of industries and will become equally important in others. The industrial chemist is making products of far greater value than corn has ever had on the farm for a great variety of industrial needs. The use of corn sugar or dextrose is increasing rapidly. The conversion of farm products into alcohol may well replace fuel which is now obtained from a steadily decreasing production of our oil fields. Sugar, too, is a highly valued product. It may well be that in the years to come our country will be on an entirely self-supporting sugar basis. It could easily absorb the sugar made from beets grown on 2,000,000 additional acres. None of the chemurgic remedies will cure agricultural ills or effect quick cures. None will put the patient on his feet unless he is willing to do his full part in the trinity of agriculture, industry, and science.

R. H. O.

WHAT ARE COSMIC-RAYS?*

BY

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INTRODUCTION.

The problems of cosmic-rays divide themselves into two classes, those concerned with the nature and origin of such radiations as enter our atmosphere from outside, and those concerned with what happens in the atmosphere itself.

Any theory of cosmic-rays must provide for the experimental facts; and these facts may be classified into the following categories:

1. Those dealing with variations of cosmic-ray intensity, and allied phenomena, such as shower production, with depth of penetration into the atmosphere and into the earth below it.
2. Those concerned with the variation of the foregoing phenomena with latitude, direction and even with longitude.
3. Those dealing with the less cosmological aspects of the phenomena, and having to do more with the detailed characters of the radiations themselves, their energy distribution characteristics, the proportion of different kinds in the atmosphere, their shower producing characteristics, and so forth.

From the beginning of cosmic-ray studies, we have been led to contemplate the possibility of there being various types of rays having different degrees of penetrability. Such ideas have within recent years crystallized themselves more or less definitely into a recognition of two components, a hard component and a soft component. The latter seems to be characterized by a reasonably definite absorption coefficient, while the former shows increase of penetrability with depth.

* Based upon a paper read at the Chicago Cosmic-Ray Symposium, June 29–30, 1938.

In speaking of two components of this kind, we always have to recognize that there are two main possibilities as regards the interpretation of our actual observations. The first of these, which seems to have been the one almost universally adopted, envisages two kinds of radiation, distinct in physical characteristics, and more or less independently responsible for the two components concerned. The second, which I think must claim attention, pictures the two components as simply an analysis into this form of some radiation whose primary elements are all alike in general physical characteristics and differ from one another only in such characteristics as energy.

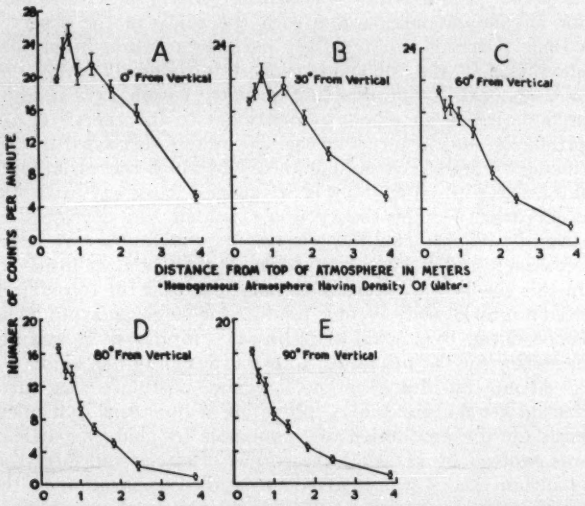
The most naïve view as to the nature of what we observe as cosmic-rays is that they represent the primary ray entities which, presumably, enter our atmosphere from outside. While such a view might have been a reasonably successful candidate for recognition twenty years ago, phenomena of increasing richness and complexity have developed which render such a view untenable. In the first place, the discovery of a latitude effect by A. H. Compton and J. C. Clay demanded primary charged particles, and fixed lower limits for entry at different latitudes. The primary charged particles with sufficient energy to enter at the magnetic equator could travel ten times the thickness of the atmosphere without losing all of their energy, if energy loss were confined to ionization. The view that primary particles represented the observed entities left, therefore, no basis for a variation of intensity with altitude in equatorial regions unless more involved processes of energy loss could be assumed, processes which in actuality suggested the probable existence of secondaries as vital participants in the story.

The phenomenon of cosmic-ray showers became realized with increasing force as an experimental reality; and an examination of the properties of the shower rays indirectly, and by the ever-increasing perfection in technique of the cloud chamber, presented us with visible evidence of charged particles which carry far too little energy to permit of their having traversed the whole atmosphere. Having revealed, in the work of C. Anderson, the existence of the positive electron, the cloud chamber also revealed many other possibilities, until

finally, in the hands of J. C. Street and E. C. Stevenson, and independently in the work of C. Anderson, it has brought to light the "heavy electron," now usually referred to as the "barytron."

Turning to more direct evidence from field observations in the atmosphere itself, the intensity altitude observations revealed a suspension of rapid increase of intensity with altitude

FIG. 1.



until finally in the work of E. Regener [1] and in the observations made on Nov. 11, 1935, by the Bartol Research Foundation on the National Geographic U. S. Army Air Corps stratosphere flight of Explorer II [2] a definite maximum to the intensity as measured with cosmic-ray counters was observed at depths the equivalent of about one meter of water below the top of the homogeneous water equivalent atmosphere, see Fig. 1.

[1] E. Regener and G. Pfotzer, *Nature*, 136, 718 (1935).

[2] W. F. G. Swann, G. L. Locher, and W. E. Danforth, National Geographic Society, Contributed Technical Papers, Stratosphere Series, No. 2, 13 (1936).

The existence of this maximum has been verified in more recent experiments by the work of R. A. Millikan [3] and his collaborators and by the work of T. H. Johnson,[4] S. A. Korff,[5] and others. It receives a ready explanation in theories which invoke secondaries as essential elements in the story, but is wholly inexplicable on a basis which confines its attention to the primaries alone.

Five years ago,[6] I showed that even with the meager data on shower production then available, it was possible to account for an amount comparable with the whole of the observed cosmic radiation as secondary particles resulting from such showers. In the following year, I introduced, purely empirically, the hyopthesis that primary cosmic-rays produce secondaries to an extent proportional to the energy of the primaries; and in terms of this hypothesis succeeded in producing a form of corpuscular theory in which the variation of intensity with altitude was in general harmony with the observations.[7] The theory was extended and developed in several papers,[8, 9] for the purpose of providing a correlation between it and the various experimental phenomena involved. In this theory I was careful to point out that the secondaries need not necessarily become produced in single acts, but could be produced by a train of processes. Moreover, it was not necessary for the primaries to be entities all of one kind.

About the time that the foregoing postulate was introduced, a quantum theory providing a quantum dynamical basis for the production of secondaries by charged particles was evolved by H. A. Bethe and W. Heitler; and later this quantum theory was invoked in detailed application to the problems of cosmic-rays. Prominent among the workers in this development are H. J. Bhabha and W. Heitler,[10] J. F. Carlson and J. R. Oppenheimer,[11] and L. W. Nordheim.[12]

[3] R. A. Millikan, H. V. Neher, and S. K. Haynes, *Phys. Rev.*, **50**, 992 (1936).

[4] T. H. Johnson, JOUR. FRANK. INST., **223**, 339 (1937).

[5] S. A. Korff, L. F. Curtis, and A. V. Astin, *Phys. Rev.*, **53**, 14 (1938).

[6] W. F. G. Swann, *Phys. Rev.*, **44**, 1025 (1933).

[7] W. F. G. Swann, *Phys. Rev.*, **46**, 828 (1934).

[8] W. F. G. Swann, *Phys. Rev.*, **47**, 250 (1935); *Phys. Rev.*, **48**, 641 (1935); *Phys. Rev.*, **50**, 1103 (1936).

[9] W. F. G. Swann, *Ohio Jour. Science*, **35**, 311 (1935).

[10] H. J. Bhabha and W. Heitler, *Proc. Roy. Soc.* **A159**, 432 (1937).

[11] J. F. Carlson and J. R. Oppenheimer, *Phys. Rev.*, **51**, 220 (1937).

[12] L. W. Nordheim, *Phys. Rev.*, **51**, 1110 (1937); *Phys. Rev.*, **53**, 694 (1938).

The quantum theory has had considerable success in accounting for the general phenomena associated with the soft component, and its story as regards the growth of small showers has been actually experimentally verified, as have the energy losses which it predicts for electrons; but the demands upon it have become more critical as the story of all the details have been sought in it.

Before the advent of the quantum theory of the soft component, the story of the primary rays was beset with considerable ambiguity. There was the question of whether we must consider two kinds of primary rays, one for the soft component and one for the hard, or whether the hard and soft components were simply different manifestations of the activities of one kind of primary entity. Indeed, the possibility of a composite group of primary entities composed of alpha particles, protons, and other radiations, has from time to time been on the board for consideration. I suppose the conventional view today is to the effect that the soft component is satisfactorily accounted for in terms of primaries which are ordinary electrons, and this leaves the remainder of the mystery for the hard component primaries.

In all these considerations one has to take account of the generally accepted conclusion to the effect that the primary charged particle rays are preponderatingly positive, a conclusion which we owe initially to the experiments of T. H. Johnson and J. C. Street,[13] and later to the simultaneous confirmation of the result[14] by T. H. Johnson, and by L. Alvarez and A. H. Compton.

SHOWER PHENOMENA OF THE HARD COMPONENT.

Experiments Performed in a Mine at 100 Feet Depth.—In spite of the beauty of form and success of application of the quantum theory to the soft component, there are one or two points which demand, I think a little further consideration. In the first place, the production of secondaries and of showers cannot be relegated, on the basis of the quantum theory, entirely to electrons. Last November, Mr. W. E. Ramsey and

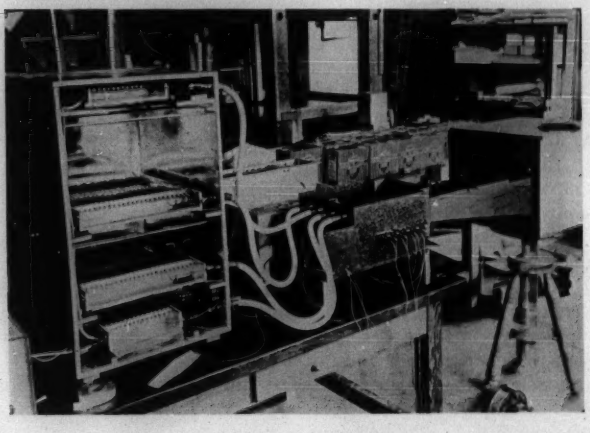
[13] T. H. Johnson and J. C. Street, JOURNAL OF THE FRANKLIN INST., 214, 665 (1932).

[14] T. H. Johnson, *Phys. Rev.*, 43, 834 (1933); L. Alvarez and A. H. Compton, *Phys. Rev.*, 43, 835 (1933).

I [15] described before the American Philosophical Society certain experiments performed at sea-level and in a mine 100 feet deep, in which we investigated shower phenomena with and without lead.

The apparatus, Fig. 2, comprised essentially four trays of cosmic-ray counters, arranged parallel to one another, and separated by distances, so that the whole formed a kind of telescope.

FIG. 2.



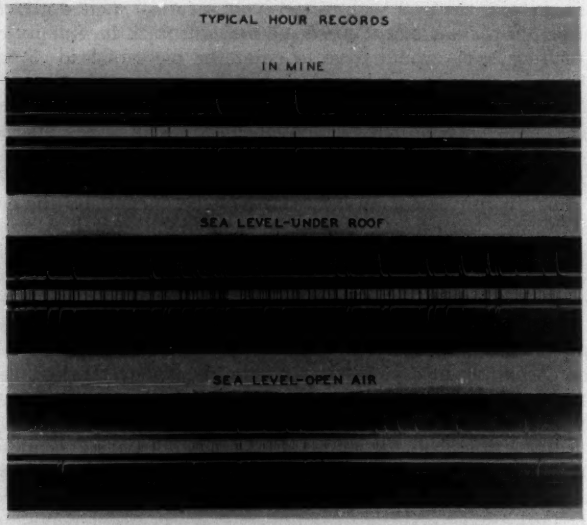
The records were obtained upon moving photographic paper, in which, along the central axis, was recorded in the form of dark lines each "event" which we define as the simultaneous discharge of at least one counter in each of the four counter areas. Above and below the center portion was recorded, in the form of electroscope deflections, a quantity indicative of the number of individual rays passing through the upper and lower of the two central counter areas, and corresponding to an "event." Fig. 3 is a sample of the kind of record obtained; and in all about 300 feet of such records were

[15] W. F. G. Swann and W. E. Ramsey, Meeting of American Philosophical Society, November 26, 1937.

obtained, covering cases (1), where there was no lead in the apparatus, and (2), where above each of the central trays a slab of lead 6 mm. in thickness was inserted.

In the absence of the lead, it was found that, on the average, the number of showers of any size per single ray was practically the same in the mine as in the attic of our Swarthmore laboratory, with the apparatus covered by thick slabs of marble, to duplicate the conditions in the roof of the mine.

FIG. 3.



Again in the absence of lead, it was found that, on the average, the total number of rays (as obtained from the showers) passing through the telescope system was 1.6 times the number of "events." It is of profound interest to determine, if possible, whether the extra rays are or are not electrons. In order to obtain information on this matter, we have made use of the experiments with lead. Calling A the upper piece of lead and B the lower, it was found that the

ratio of the total number of shower rays emerging from B to the number emerging from A was 1.3 where, by the number of shower rays in each case, we mean the number of rays in excess of the number of single rays which are always associated with any recorded "event."

We may now make the tentative hypothesis that the hard component rays do not produce showers appreciably in the lead, and ask what the average energy of a group of electrons would have to be in order that, through the processes of the quantum theory, they would result in the production of showers in the lead such as to give the ratio 1.3 cited above. The answer is 2×10^8 e.v. We may then ask how many of such electrons would have to enter the piece of lead A per hour in order to produce, on emergence from that piece of lead, the number of shower rays found per hour. The answer is 7. This is approximately equal to 7.5, which represents the difference between the total number of rays recorded per hour *in the absence of the lead*, and the number of "events" recorded. Thus, there is harmony between the experiments and the assumption that each "event" is associated with one hard ray, which rays themselves produce negligible showers in the lead, but which are accompanied by electrons to the extent of 0.6 of their number and of energy 2×10^8 e.v.

Although the experiments are consistent, to a first approximation, with neglect of direct shower production by the hard component rays in the lead, we must, nevertheless, assume that it is the showers produced by the hard component in the substance of the earth which, in actuality, represent the electrons found in the mine, since neither primary cosmical electrons of reasonable energy nor their progeny produced by multiplication could penetrate to the depths concerned. It is natural to regard the hard component shower phenomenon as one occurring at rare intervals, possibly with the ejection, on these occasions, of a few or even one particle with high energy. If this particle is an electron, or gives rise to electrons, these electrons, through the ordinary quantum theory processes, may be expected to constitute or to give rise to such shower producing electrons as were to be found in the mine.

Simultaneity in Cosmic-Ray Phenomena.—The shower phenomena existing in the absence of lead present interesting

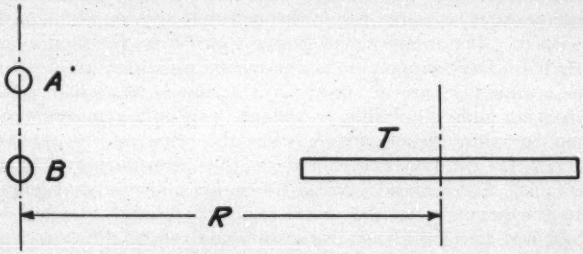
questions. Thus, by adding up all of the different rays obtained in different showers, it is possible to inquire how many rays, on the average, accompany any event within the limits of our recording apparatus. The results in the mine indicated that, on the average, ten events were accompanied by an additional six rays. The numerical information obtained in this way is subject to some ambiguities as to its interpretation, depending as it does upon the form of the apparatus. Into these matters I will not, for the moment, enter. A fundamental problem of rather vital significance becomes, however, raised and may be cited in the following form:

Suppose that we had an apparatus capable of measuring the rays over a very large area, an infinite area in the limit. Concentrating our attention on any one ray which, at the moment, is passing through the area, we may inquire how many other rays are passing through that area simultaneously with it. The interest of this story, of course, lies in the fact that if a large proportion of the radiations which we measure as cosmic-rays are of shower origin, those rays which come from an individual shower should be simultaneous in their passage through any plane below the origin of the shower. Even if a primary ray should produce secondaries all along its path, and if these secondaries should be inclined at angles to the primary, so that their times of passage through an assigned horizontal area were different, those differences in time would be negligible within the limits of resolution of our apparatus, since the rays travel with velocities comparable with the velocity of light. An examination of the simultaneity of different measured rays contains, therefore, information as to their shower origin. This matter was referred to in my "Report of the Director of the Bartol Research Foundation" of April 1936, and since that time we have made various investigations having a bearing upon the subject, including the mine experiments referred to. Recently, Mr. Ramsey and I carried out a preliminary investigation of the matter in a manner designed to eliminate as far as possible many of the disturbing elements concerned with it. In principle the procedure is as follows:

We have a Geiger Counter telescope AB, Fig. 4, and we have an area T of Geiger Counters which can be placed in any

position in relation to AB, and which is so arranged in relation to its accompanying electrical equipment that it is allowed to operate only when a ray goes through AB; and, under these conditions, it records the number of rays which pass through it simultaneously. By making measurements with this area of counters at varying distances from AB, and by suitably integrating the results for any distance over the circular ring which the counter area would describe if rotated around AB as axis, we can obtain for the whole infinite horizontal plane extending out from AB the average number of singles, doubles, or triples, etc., passing through the area for any number of assigned rays going through AB. To cut a long story short, we can inquire how many rays on the average

FIG. 4.



pass through the infinite plane simultaneously with any one ray passing through AB.

We have extended our observations up to distances comparable with 150 cms. from AB; and even at these distances there are occasionally rays which occur simultaneously with rays through AB. Confining our attention to no more of the infinite plane area than is comprised by the 150 cms. radius aforesaid, we find that a ray through AB, and therefore in general any other ray, is accompanied, on the average, by 0.5 other rays in the space around.

The extension of the simultaneous rays to such large distances from AB is difficult to harmonize with the belief that each simultaneous group originates in a single center on the roof material in the attic where the experiments were

performed, since this material is only about five feet above the apparatus. One is led to think of their originating at much greater vertical distances in the atmosphere itself. One is led to think of their representing progeny of a single event associated with the entry of a primary electron into the atmosphere, in which case they form constituents of what we know as the soft component. Another supposition is that they represent particles emitted along the path of a hard component primary. Such particles would arrive, to all intents and purposes, simultaneously at the plane of observation.

The view that the simultaneous rays here considered form part of the soft component progeny encounters difficulty from the fact that the sizes of the showers developed in the roof of the attic are such as to suggest that the electrons responsible for them have energies of an order of magnitude between 10^9 e.v. and 10^{10} e.v.; and for such energies we must look to some other source. The only obvious source available is the hard component.

Suppose, therefore, that a hard component primary experiences β times, per unit of path, an "event" in which it emits a secondary with an energy of 5×10^9 e.v. The average angle of divergence of such a secondary from the original path of the primary is of the order 1.4×10^{-2} radians,[16] so that the path of the primary which contributes secondaries to the circle of radius 1.5 meters is about 100 meters of air, or 0.1 meter of water equivalent. The number of such rays falling within the circle of 1.5 meters radius will be $0.1\,\beta$. If the rays experienced, in the 1 foot concrete roof, multiplication such as would be characteristic of electrons of energy 5×10^9 e.v., we should expect, within the aforesaid circle, below the roof, about $0.4\,\beta$ shower rays as corresponding to one primary ray.[17] Equating this to 0.5, the experimental value already cited, we obtain $\beta \sim 1$. In other words, the results are in harmony with the view that, associated with the hard component, there are losses of the order 5×10^9 e.v. occurring in the atmosphere, with a frequency of the order 1 per meter of water equivalent path.

[16] W. Heisenberg, *Annalen der Physik*, 13, 430 (1932); see also W. F. G. Swann, JOUR. FRANK. INST., 220, 373 (1935).

[17] H. J. Bhabha and W. Heitler, *Nature*, 138, 40 (1936).

Incidentally, it may be observed that the invocation of relatively frequent losses of energy of large amount by the hard component renders more readily understandable than would otherwise be the case the production of such very large showers as are occasionally observed.

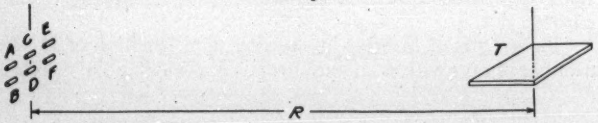
The main purpose of the foregoing discussion is to show that the existence of a state of affairs in which, below the roof, there is on the average at least 0.5 ray which is simultaneous with every other in a 1.5 meter radius, is a situation which is in harmony as regards order of magnitude with the thought that the secondaries in question arise ultimately from particles emitted with considerable energy and frequency by the hard component. An attempt to explain the origin of these rays as arising in the soft component would meet great difficulties in accounting for the number, and still greater difficulties when attempt was made to apply it to our data for the mine.

At first sight, it might be thought that the mechanism we have envisaged would result in there being about 1.5 times the measured cosmic-ray intensity below the roof as occurs above it. This is not so, however, for the roof also performs the function of eliminating the lower energy electron rays which enter it above, and which, in its absence, would have reached the apparatus below. The elimination of these rays more than counteracts the addition of the shower rays which have been referred to so that the net result is a diminution in the over-all measured intensity. The story here is quite analogous to that encountered in the ordinary quantum theory of secondary production by electrons in the atmosphere, and according to which, in spite of what would be an increase in the number or rays with depth of penetration in the absence of ionization loss, there is, in actuality, a decrease with penetration after a sufficient depth is attained.

It may be stated that the counter telescope AB referred to in the foregoing discussion was, in actuality, replaced by three independent telescope sets, Fig. 5, so as to enhance the rate of accumulation of results. The arrangements of the elements of these telescopic units was such as to prevent the operation of the shower measuring set except when a ray passed through one of the upper members of the telescopic

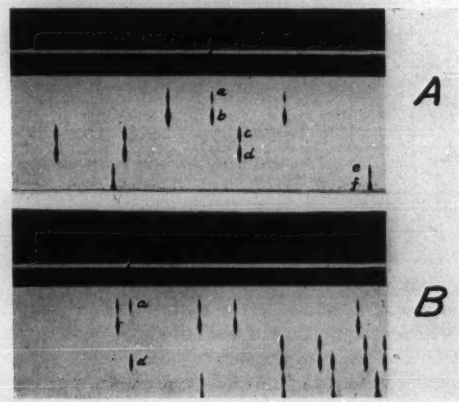
units and one of the lower members. However, since the desire was to confine attention to rays which passed only through the individual members of the same telescope, some means for eliminating such rays as would pass through *C* and *B*, for example, was necessary.

FIG. 5.



To this end every counter which discharged was allowed to record, provided that at least one member of the top set and one member of the bottom set discharged simultaneously, and no counter was allowed to record unless this happened.

FIG. 6.

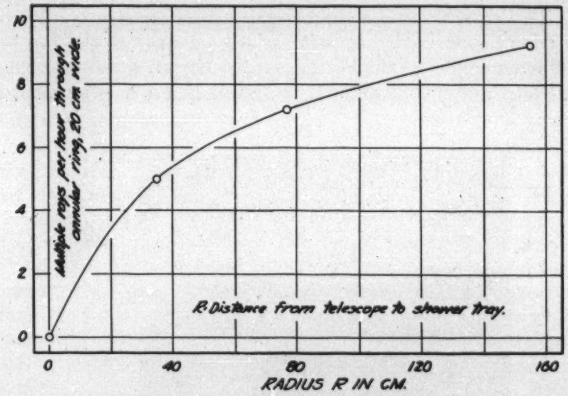


The records were made by means of light spots, one corresponding to each of the six counters. Thus, for example, in the trace in Fig. 6*A*, the spots *a*, *b*, *c*, *d*, *e*, *f* correspond to counters *A*, *B*, *C*, *D*, *E*, *F*. We have a record of a shower, and on the same record we have spots *a* and *b* corresponding

to the counters A and B. We know that this is a shower corresponding to a ray which passed through A and B. On the other hand, in Fig. 6B, we have a situation which sometimes occurred. A shower is recorded, but it is associated with the dots a and d which correspond to the counters A and D, and these two counters do not form part of one vertical telescopic system. For this reason, such records were discarded.

Figure 7 is of interest in showing as a function of R, the number of rays within an annulus 20 cms. wide and of average

FIG. 7.

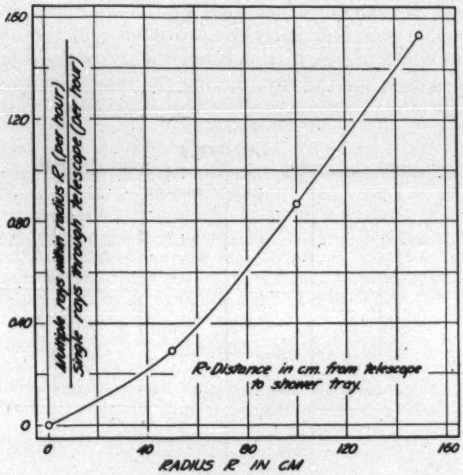


radius R simultaneous with the passage of a ray through one of the telescopic systems. It is of interest to note that the curve continues to rise, and at least does not approach a falling form within the limits of the measurements. In other words, as we proceed outwards from AB, successive annuli pay contributions which at least do not decrease with R. In fact, the diminution of number of rays per unit area with distance from the telescopic counter is more than balanced by the increase of area of the annulus. How far this horizontal feature of the curve extends, we do not know; and the greater the distance of its extension, the greater the number of rays

which, on the average, are to be regarded as simultaneous with any one ray.

Figure 8, obtained by integration, gives, as a function of R, the total number of simultaneous rays falling within the radius R.

FIG. 8.



REVIEW OF POSSIBILITIES INHERENT IN FORMER CORPUSCULAR THEORIES.

In spite of the almost universal acceptance of the quantum theory of the soft component, I think it is of interest to trace the possibilities inherent in earlier and closely related views.

In the first place, we may treat the soft component and the hard component as representative of distinct phenomena, or we may seek both in the same primary background.

Confining attention for the moment to the soft component, and in particular, to the primaries associated with it, we may suppose that, in addition to the regular loss by ionization, there is some other loss depending upon the energy of the ray, or independent of that energy as a limiting case. Such views lead as a rule, to a condition in which there is a range for each ray

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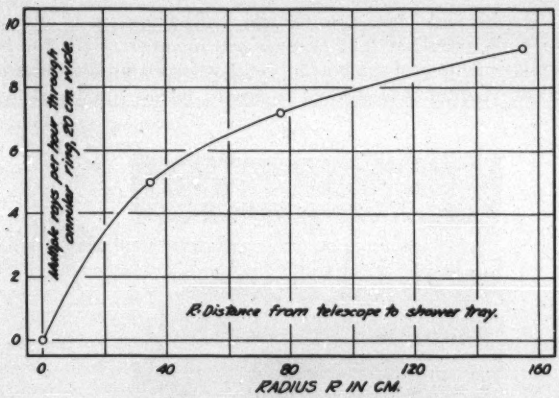

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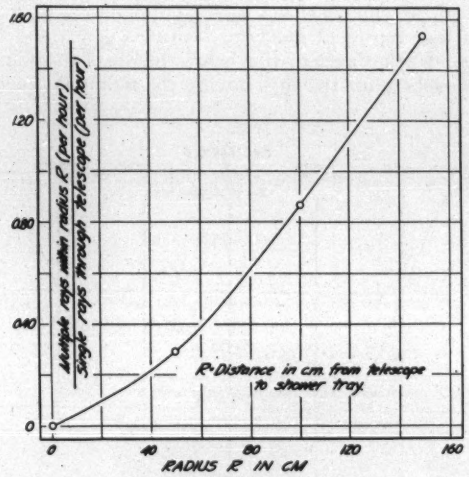

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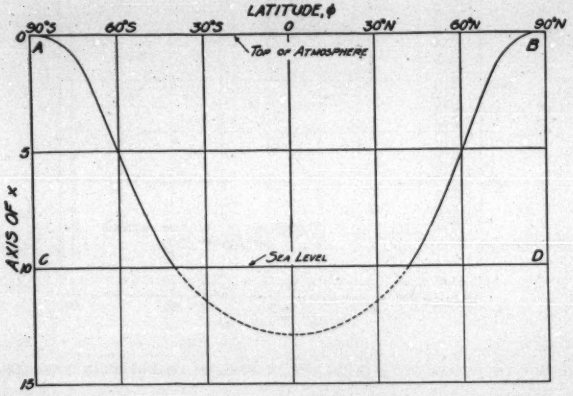
Confining attention for the moment to the soft component, and in particular, to the primaries associated with it, we may suppose that, in addition to the regular loss by ionization, there is some other loss depending upon the energy of the ray, or independent of that energy as a limiting case. Such views lead as a rule, to a condition in which there is a range for each ray

depending upon its energy. Those rays which have energy enough to penetrate the earth's magnetic field will succeed in reaching to a certain depth in the atmosphere without diminution of their number. The higher the lower limit of the energy for entry through the magnetic field, the greater the depth of penetration without loss, so that as far as the primaries are concerned, we can construct such a curve as Fig. 9, in which the abscissæ represent magnetic latitudes, and the ordinates represent depth of penetration below the top of the homogeneous atmosphere for the rays having the minimum energy for

FIG. 9.



entry. In regions above this curve there is no variation of primary intensity with altitude, and such variation of intensity with altitude as exists in these regions must be sought in the secondary phenomena aforesaid. Below the critical curve both primaries and secondaries function. It results from rather general considerations that if the primaries in the regions below the critical curve experience an exponential absorption, they will transmit to the secondaries an apparent exponential absorption, whatever the law governing the relation between secondary production and energy may be. On the other hand, above the critical curve the increase with

altitude is determined entirely by the secondaries, and the coefficient is determined by the laws governing their rate of loss of energy and production. If this critical curve is not so high above the earth, or so far below sea-level, as to be outside the region of possibility as regards satisfactory observation, we are confronted with the necessity of providing for a continuity of absorption coefficient between the two regions.

Taking the case where the loss of energy of a primary ray is governed by an equation of the type [18]

$$-\frac{dE}{dx} = \lambda E + \alpha$$

it is easy to show that the spectral distribution function $F(E)$

[18] It is of interest to notice a close parallel between the results of the quantum theory, and the assumptions $-dE/dx = \lambda E$, and $n = \sigma E$ characteristic of my 1934 paper.[7] If α is the energy lost by a ray per unit of path in ionization, η the average energy of all the rays at any depth x, and n the intensity of all the rays, then the fact that the energy is ultimately lost by ionization subjects the quantum theory process to the control of the equation

$$\frac{-d(n\eta)}{dx} = \alpha n. \qquad (1)$$

Now if E is the *energy of the whole entity composed of the primaries and their progeny*

$$E = n\eta \qquad (2)$$

A combination of (2) and (1) leads to

$$-\frac{dE}{dx} = \frac{\alpha}{\eta} E. \qquad (3)$$

Equations (2) and (3) are of the form of the assumptions of my 1934 paper when η is independent of x; so that in a sense, the quantum theory represents a particular case of those empirical assumptions, with the primary entity replaced by that whole entity of progeny which results from the entry of a single electron into the atmosphere. Equations (2) and (3) contain, of course,

$$-\frac{dn}{dx} = \frac{\alpha}{\eta} n$$

so that the coefficient of absorption μ is $\mu = \alpha/\eta$. Now $\alpha = 10^8$ e.v. per meter of water equivalent. If μ is to have the value 0.5, we must have $\eta = 2 \times 10^8$ e.v., which value is quite in harmony with experiment.

If η is not independent of x, (1) can nevertheless be written

$$-\frac{dn}{dx} = \left(\frac{\alpha}{\eta} + \frac{d}{dx}\log \eta\right) n$$

so that $\mu = \frac{\alpha}{\eta} + \frac{d}{dx}(\log \eta)$.

necessary to secure exponential absorption for the primaries is

$$F(E) = \frac{A}{(E + \alpha/\lambda)^p} \tag{4}$$

or approximately

$$F(E) = \frac{A}{E^p} \tag{5}$$

Now the Latitude effect of the primaries is determined by the exponent p and is greater the greater the magnitude of that exponent. The coefficient of absorption of the primaries in regions where they are absorbed at all is $\mu = (p - 1)\lambda$, and the apparent coefficient for the secondaries is $s\lambda$, where the number of secondaries accompanying a primary is proportional to E^s. The equality of these coefficients necessitates that $(p - 1) = s$; and with this condition it turns out that, regardless of the value of s, the secondary intensity at the top of the atmosphere is proportional approximately to $\log_e (E_m/E_\varphi)$ where E_φ is the energy for entry through the magnetic field and E_m is an upper limit to the energy of the spectral distribution which, unless it be assumed finite, results in an infinite value for the secondary intensity at all altitudes. The apparent paradox in this matter is, of course, provided for in line with the conservation of energy by the prediction of a zero average of energy for the secondary rays. However, the assumption of a finite upper limit gives a finite soft component intensity, and the smaller the upper limit the greater the latitude effect at the top of the atmosphere.

In the paper containing the details of this matter,[19] λ was determined so as to provide for a penetration of atmosphere for the rays of energy 6×10^9 e.v. which enter the atmosphere at the magnetic latitude where the latitude effect ceases to increase further with latitude. The value of λ was 0.33 and necessitated a value $s = 1.5$ in order to give an absorption coefficient of 0.5.

The latitude effect of the soft component secondaries is independent of altitude and it was necessary to assume a hard component of different nature showing no latitude effect, so as to iron out the latitude effect of the soft component secon-

[19] W. F. G. Swann, *Phys. Rev.*, **50**, 1104 (1936).

daries, and indeed, of the soft component primaries, near the earth's surface, to a resultant value consistent with the facts. It will be recalled that the sea-level latitude ratio between 42° magnetic latitude and the magnetic equator is about 1.14.

The fact that, in practically all forms of theory which treat the soft and hard components separately, the latitude effect of the soft component comes out practically independent of altitude, makes the process of ironing it out at sea-level by the hard component, showing no latitude effect, an almost inevitable procedure.

In the former paper [19] to which I have referred, it is shown that the theory along the general lines stated can be made to harmonize with a wide variety of facts. The details of the theory are susceptible of some adjustment. Thus, for example, there are certain advantages in assuming a value of $\lambda = 0.5$, so that the corresponding value s becomes unity. Indeed, such a procedure, while not inevitably demanded by (1) is strongly suggested by it. Such a value of λ is not readily adapted to a sea-level cessation of latitude effect at 42°. However, these matters concern more or less details, and do not affect the fundamental essentials.

As already implied, the quantum theory has provided for electrons characteristics which prevent us from accepting them as the primaries of the soft component in a theory of the foregoing kind, and we must look for some other particles. This leaves us with the undesirable task of looking for still other particles to provide for the hard component. The tempting idea of taking the primaries of the soft component and causing them to function also as the hard component by modifying the spectral distribution function slightly so as to permit of diminution of absorption coefficient with depth is ruled out by the fact that the soft component has a larger latitude effect than the secondaries themselves. A way of escape is open by supposing that in addition to the primary particles responsible for the soft component there is another group of entering particles of the same kind, but with a different energy distribution. If we suppose this second group to have a lower limit of energy which is, nevertheless, higher than the minimum energy for entry through the magnetic field, we shall succeed in robbing it, and any secondaries which

it produces, of latitude effect. By choice of an inverse power of E function for the spectral distribution of this group, we can so choose the exponent as to give any absorption coefficient desired for the primaries. By having a number of such groups with different exponents, we can produce a resulting absorption coefficient which varies with depth. I think there is nothing particularly arbitrary about the assumption of such groups of rays. The arbitrariness is apparent rather than real, for mathematically these various groups with their different exponents of E can be regarded as simply mathematical expansion in power series form of a general spectral distribution function, whose form is determined by cosmological considerations outside of the realm of the theory. Any element of artificiality is to be found in the assumption of a lower limit; and even this is less surprising physically than it is mathematically; for a lower limit to energy in groups of rays traveling about in interstellar space is by no means a disagreeable concept. A nightmare of a cosmological physicist might reveal many galactic magnetic fields ready to devour or imprison the weaker members of ray groups.

Further complication, however, arises from the fact that the exponents p in the spectral distribution for the hard component are smaller than for the soft component, and this means that since the soft component secondaries would develop an infinite intensity but for the assumption of an upper limit to the primary energy, an upper limit is even more necessary for the hard component primaries. However, perhaps an upper limit is no serious physical barrier. The real difficulty arises from another aspect of the secondaries. To assume without reason an absence of secondaries from the hard component primaries would simply be to endow them with characteristics different from those of the soft component primaries, and would be illogical. On the other hand, if we permit the secondaries to form by the same laws as for the soft component primaries, their contribution will show an increase with altitude with the same coefficient as for the soft component secondaries, and since the hard component primaries must dominate the soft component primaries at sea-level, in order to iron out the latitude effect, the hard component secondaries will dominate the soft component secon-

daries at the top of the atmosphere and iron out the latitude effect there where we do not want it ironed out.

Although we may not, without comment, deny for the hard component primaries the property of producing secondaries, we may perhaps secure the same end by the mathematical subterfuge of supposing that the law which makes the energy loss in secondary production proportional to E is only an approximation to a more general form in which E is replaced by $f(E)$, and f is a function which reverts the form λE for sufficiently low energies and to a form of a small fractional power of E, or even to a form independent of E for high energies. In the case where $f(E)$ becomes independent of E, the secondaries, of course, become everywhere proportional in intensity to their primaries. In this case, moreover, the ionization loss and the loss in secondary production both combine to produce a constant loss per unit of path, and we have, of course, a corresponding range phenomenon.

Certain Interesting Consequences of the Range Phenomenon. —In the case of a distribution function $F(E) = A/E^p$, and with a constant loss of energy γ per unit of path, the intensity N_x at a depth x (for which γx is greater than the energy for entry through the magnetic field) is

$$N_x = \int_0^\infty \frac{A dE}{(E + \gamma x)^p} = A \int_{\gamma x}^\infty \frac{d\zeta}{\zeta^p} = \frac{A}{(p-1)(\gamma x)^{p-1}}. \quad (6)$$

The average energy $\bar{E}_x$ at the depth x is given by

$$N_x \bar{E}_x = \int_0^\infty \frac{AE dE}{(E + \gamma x)^p} = A \int_{\gamma x}^\infty \frac{\zeta d\zeta}{\zeta^p} - A\gamma x \int_{\gamma x}^\infty \frac{d\zeta}{\zeta^p}$$

$$= \frac{A}{(p-2)(\gamma x)^{p-2}} - \gamma x N_x,$$

$$\bar{E}_x = \left(\frac{p-1}{p-2}\right) \gamma x N_x - \gamma x N_x$$

$$\bar{E}_x = \frac{\gamma x}{p-2}. \quad (7)$$

Also, it follows immediately from (6), and is, indeed, well known, that

$$\mu = \frac{p-1}{x}. \quad (8)$$

Equations (7) and (8) would serve to determine p and γ by observation of this coefficient of absorption and the average energy of the rays at any depth x.

Now, by integrating the total ionization below successively increasing depths, Dr. and Mrs. Montgomery [20] have obtained the energy in the rays at any depth; and by dividing them by the numbers of rays at the various depths, they have obtained the average energy of a ray at any depth. They find that below 10 meters of water equivalent depth, where the hard component may be assumed dominant, there is a linear relationship between the average energy and the depth, the increase being about 2.4×10^8 e.v. per meter of water equivalent.

Again the coefficient of absorption at depths comparable with 20 meters of water approximates to the form $\mu = 1.87/x$.

If we apply these experimental data to (7) and (8) on the assumption that all the rays observed at the depths are primaries, we obtain

$$2.4 \times 10^8 = \gamma/(p - 2),$$
$$1.87 = p - 1,$$

giving

$$p = 2.87, \tag{9}$$

$$\gamma = 2 \times 10^8. \tag{10}$$

As we shall see later, the significance of the foregoing conclusions becomes modified considerably as regards γ, if we invoke secondaries as an accompaniment to the primary rays.

These considerations with regard to the hard component have very little to do with those elements which are so vitally concerned in the soft component, and which have to do with a region where the primaries do not alter in intensity with altitude until a depth of penetration is reached such that the range for the energy of entry is equal to that depth. The whole theory of the soft component in the form sketched is bound up with the range phenomena and with its relation to the magnetic field. I have dealt with the matter in some detail in order to exhibit both the weakness and strength of this particular view. The assumption contains some artificial

[20] C. G. and D. D. Montgomery, *Phys. Rev.*, **53**, 193 (1938).

elements which will be acceptable or repugnant, according to our psychology. First, we have the assumption of an upper limit and of a lower limit (in the case of the hard component). Then we have the variation law of absorption as we cross the curve which separates the region where primaries are absorbed from that where they are unabsorbed. We have, further, rather critical limitations upon the magnitude which it is possible to attain for the latitude effect at high altitudes. A large latitude effect demands a low upper limit for the soft component; but the upper limit must at least be as high as that for horizontal entry into the atmosphere from both east and west.

We may escape some of the foregoing objections by giving up the idea of a more or less continuous loss of energy by the primaries in secondary production, and assuming relatively large losses amounting in the limit to complete loss in single acts. This most drastic condition is the one farthest removed from the range phenomenon. If loss in more than one step is permitted, the characteristics of the range are gradually approached as the number of steps is increased.

A NEW FORM OF THEORY BASED UPON LARGE ENERGY LOSSES.

I propose now to develop some consequences of the idea that large energy losses can occur from the primary rays, and to show how, on the bases of such considerations, we may evolve a theory in which, from a single primary component with suitably chosen distribution function, we may develop the whole story of what is customarily regarded as the story of a soft and a hard component.

The fundamental assumptions which we shall make empirically are these:

1. Each primary ray experiences per unit of path a number of events, or collisions, the average number of these per unit of path being β. This number we assume independent of the energy of the ray, and we assume the events to be distributed individually and collectively at random in any interval concerned.

2. In each of these events the ray loses an amount of energy ϵ, which is the same for all energies. No ray of

energy E can experience more than m events of this kind, where $m\epsilon = E$.

3. If a ray has energy less than ϵ, it has nevertheless the same chance of experiencing an event; but in such an event it loses all of its energy.

4. When a primary ray loses energy, the energy loss goes into secondaries—possibly, in part, heavy electrons—and some of it gets converted directly or indirectly into ordinary electrons which then proceed according to the Bethe-Heitler theory, the energy being lost, finally, by ionization in all cases.

For the purposes of presentation, we shall, for simplicity, though not of necessity, neglect the loss of energy of the *primary rays* in ionization, and confine attention to the energy lost in the events, leaving ionization to function mainly for the secondary and higher order radiations.

Since βx is the average number of events in the interval of length x, Poisson's formula gives, for the probability P, of n events in the interval x,

$$P = \frac{(\beta x)^n}{\underline{/n}} e^{-\beta x}, \tag{11}$$

energy ϵ being emitted at each event provided, of course, that $E > n\epsilon$.[21]

Now, if $F(E)$ is the spectral distribution function, and E_φ the energy of entry at the latitude φ, we obtain for the number of rays which travel the distance x with no collisions, one collision, two collisions, etc.

$$N_0 = \frac{\beta x^0}{\underline{/0}} e^{-\beta x} \int_{E_\varphi}^{\infty} F(E)dE = e^{-\beta x} \int_{E_\varphi}^{\infty} F(E)dE,$$

with no collisions,

[21] In order to avoid any doubts as to the applicability of the formula for $n\epsilon < E$, since it cannot be applied to actual emission of energy for $n\epsilon > E$, we may distinguish in our minds between the *events* and the *energy emission* at the events, and evolve a mental picture of a ghost-like entity which goes on experiencing events—in the sense of a certain proximity of encounter—for ever. For the *events*, therefore, (11) applies for all values of n. Our *interest* in the events is confined to those which are associated with loss of energy; and these are limited by the condition $n\epsilon < E$.

$$N_1 = (\beta x)e^{-\beta x}\int_{\epsilon}^{\infty} F(E)dE, \qquad \text{with one collision,}$$

$$N_2 = \frac{(\beta x)^2}{\underline{|2}}\, e^{-\beta x}\int_{E_{2\epsilon}}^{\infty} F(E)dE, \qquad \text{with two collisions,}$$

$$N_n = \frac{(\beta x)^n}{\underline{|n}}\, e^{-\beta x}\int_{E_{n\epsilon}}^{\infty} F(E)dE, \qquad \text{with } n \text{ collisions,}$$

where

$$E_{n\epsilon} = E_\varphi \qquad \text{if} \qquad n\epsilon < E_\varphi$$

and

$$E_{n\epsilon} = n\epsilon \qquad \text{if} \qquad n\epsilon > E_\varphi.$$

Writing

$$I_\varphi \equiv \int_{E_\varphi}^{\infty} F(E)dE \qquad \text{and} \qquad I_{n\epsilon} \equiv \int_{E_{n\epsilon}}^{\infty} F(E)dE$$

we have, for the total intensity of the primaries

$$N = e^{-\beta x}\left[I_\varphi + \beta x I_\epsilon + \frac{(\beta x)^2}{\underline{|2}} I_{2\epsilon} + \cdots \frac{(\beta x)^n}{\underline{|n}} I_{n\epsilon} + \cdots \right]. \qquad (12)$$

Now, concerning this expression the following points may be noted:

1. Only the first term gives a true exponential absorption, the absorption coefficient being equal to β.

2. The effect of the terms other than the first is to cause the absorption coefficient, defined as $-d(\log N)/dx$ to vary with x. At $x = 0$, $\mu = \beta(1 - I_\epsilon/I_\varphi)$; and indeed, for the case where $I_\epsilon = I_\varphi$, i.e. where $\epsilon < E_\varphi$, the absorption coefficient is zero at $x = 0$. With increasing x it attains a maximum and then decreases with further increase of x. The phenomenon proceeds to acquire more and more the characteristics of a range with increasing x, until finally, for very large values of x, the intensity passes over entirely into the form determined by the distribution function, viz.:

$$N = \int_0^{\infty} F(E + \beta\epsilon x)dE. \qquad (13)$$

3. The only terms of (12) which show a change with latitude at any particular value of φ are those for which n is less than the value given by $n\epsilon < E_\varphi$.

The first terms of the series are those which are dominant at high altitudes (small values of x), while the later numbers assume the important rôle at greater depths. There is thus secured for the primaries a condition in which the latitude effect increases with altitude. The total latitude ratio of the primaries at the top of the homogeneous atmosphere is

$$R_0 = I_\varphi / I_M.$$

The Rôle of the Secondaries.—It has been necessary to treat the primaries in some detail; but the story of what is measured is contained mainly in the secondaries. If W is the loss of energy by a primary from the top of the homogeneous atmosphere to the point x, the loss of energy per unit of path by a primary is dW/dx. Thus, if η is the average energy of a secondary and n their number, we have

$$\eta \frac{dn}{dx} + \alpha n = \frac{dW}{dx}, \tag{14}$$

where α is the loss per unit of path by ionization, and where η is assumed constant. Thus

$$\frac{dn}{dx} + \frac{\alpha}{\eta} n = \frac{1}{\eta} \frac{dW}{dx}.$$

This equation can be integrated in the form

$$n = \frac{1}{\eta} e^{-(\alpha/\eta)x} \int_0^x \frac{dW}{dx} e^{(\alpha/\eta)x} \, dx. \tag{15}$$

Now W becomes determined by the following considerations: Let us first confine our attention to the case where $\epsilon < E_\varphi$ for all values of φ concerned, and where, in fact, s is such that $s\epsilon < E_\varphi < (s+1)\epsilon$. Let us write y for βx. We shall again distinguish between encounters (or collisions) and the acts of emission of energy at collisions, adopting as already stated, the mental artifice of picturing a ray as going on for ever,

suffering collisions at random, but only emitting energy to the extent that it possesses energy.

For all collisions up to and including s collisions, a ray loses ϵ at each collision. The contribution to W on this account is, therefore, ${}_1W_s$, where

$$ {}_1W_s = e^{-y}\left[\epsilon y + \frac{2\epsilon y^2}{\underline{|2}} + \cdots s\epsilon\frac{y^s}{\underline{|s}}\right]\int_{E_\varphi}^{\infty} F(E)dE. \quad (16) $$

Now consider the energy losses involved in the case of s 1+ collisions. All rays from $E = (s+1)\epsilon$ to infinity can make $(s+1)$ collisions *only* by losing $(s+1)\epsilon$. Hence the contribution to W in this manner is W_{s+1} where

$$ W_{s+1} = e^{-y}(s+1)\epsilon\frac{y^{s+1}}{\underline{|s+1}}\int_{(s+1)\epsilon}^{\infty} F(E)dE. \quad (17) $$

However, the rays for which $E_\varphi < E < (s+1)\epsilon$ can lose all of their energy by making $(s+1)$ collisions, or any larger number of collisions. Hence the contribution to W on this account is ${}_{s+1}W_\infty$ where

$$ {}_{s+1}W_\infty = e^{-y}\left[\frac{y^{s+1}}{\underline{|s+1}} + \frac{y^{s+2}}{\underline{|s+2}} + \cdots\right]\int_{E_\varphi}^{(s+1)\epsilon} EF(E)dE \quad (18) $$

or

$$ {}_{s+1}W_\infty = \left(1 - e^{-y}\left[1 + y + \frac{y^2}{\underline{|2}} + \cdots\frac{y^s}{\underline{|s}}\right]\right) \times\int_{E_\varphi}^{(s+1)\epsilon} EF(E)dE. \quad (19) $$

In a similar manner there are two contributions to W from the losses experienced respectively by the rays which make $(s+2)$ collisions only by losing $(s+2)\epsilon$, and by the rays for which $E_{(s+1)\epsilon} < E < E_{(s+2)\epsilon}$, which rays can lose all of their energy by making $(s+2)$ or any larger number of collisions. The contributions on these accounts are

$$ W_{s+2} = e^{-y}(s+2)\epsilon\frac{y^{s+2}}{\underline{|s+2}}\int_{(s+2)\epsilon}^{\infty} F(E)dE \quad (20) $$

and

$$ {}_{s+2}W_\infty = \left(1 - e^{-\nu}\left[1 + y + \frac{y^2}{\underline{2}} + \cdots \frac{y^{s+1}}{\underline{s+1}}\right]\right) \times \int_{(s+1)\epsilon}^{(s+2)\epsilon} EF(E)dE. \quad (21) $$

Proceeding in this way, and adding up all the contributions, we obtain

$$ \begin{aligned} W = (1 - e^{-\nu}) & \int_{E_\varphi}^{\infty} EF(E)dE \\ & + \left\{ e^{-\nu} y \left[\epsilon \int_{E_\varphi}^{\infty} F(E)dE - \int_{E_\varphi}^{\infty} EF(E)dE \right] \right. \\ & + \frac{e^{-\nu}y^2}{\underline{2}} \left[2\epsilon \int_{E_\varphi}^{\infty} F(E)dE - \int_{E_\varphi}^{\infty} EF(E)dE \right] \\ & \left. + \cdots e^{-\nu} \frac{y^s}{\underline{s}} \left[s\epsilon \int_{E_\varphi}^{\infty} F(E)dE - \int_{E_\varphi}^{\infty} EF(E)dE \right] \right\} \\ & + \left\{ \frac{e^{-\nu}y^{s+1}}{\underline{s+1}} \left[(s+1)\epsilon \int_{(s+1)\epsilon}^{\infty} F(E)dE \right. \right. \\ & \qquad \left. - \int_{(s+1)\epsilon}^{\infty} EF(E)dE \right] \\ & + \frac{e^{-\nu}y^{s+2}}{\underline{s+2}} \left[(s+2)\epsilon \int_{(s+2)\epsilon}^{\infty} F(E)dE \right. \\ & \qquad \left. \left. - \int_{(s+2)\epsilon}^{\infty} EF(E)dE \right] + \cdots \right\}. \end{aligned} \quad (22) $$

If we should consider the case where $\epsilon > E_\varphi$, the contributions of the forms ${}_1W_s$ would be absent, W_{s+1} would become W_1, ${}_{s+1}W_\infty$ would become ${}_1W_\infty$, and we should have

$$ \begin{aligned} W = (1 - e^{-\nu}) & \int_{E_\varphi}^{\infty} EF(E)dE \\ & + \left\{ e^{-\nu} y \left[\epsilon \int_{\epsilon}^{\infty} F(E)dE - \int_{\epsilon}^{\infty} EF(E)dE \right] \right. \\ & + e^{-\nu} \frac{y^2}{\underline{2}} \left[2\epsilon \int_{2\epsilon}^{\infty} F(E)dE \right. \\ & \qquad \left. \left. - \int_{2\epsilon}^{\infty} EF(E)dE \right] + \cdots \right\}. \end{aligned} \quad (23) $$

Using (5), we find from (22), after a little reduction, for $\epsilon < E_\varphi$

$$
\begin{aligned}
W = \frac{A}{(p-1)E_\varphi^{p-1}} \Bigg\{ & \left(\frac{p-1}{p-2}\right) E_\varphi (1 - e^{-y}) \\
& + \left[e^{-y} y \left(\epsilon - \frac{p-1}{p-2} E_\varphi \right) \right. \\
& + \frac{e^{-y} y^2}{\underline{|2}} \left(2\epsilon - \frac{p-1}{p-2} E_\varphi \right) \\
& \left. + \cdots e^{-y} \frac{y^s}{\underline{|s}} \left(s\epsilon - \frac{p-1}{p-2} E_\varphi \right) \right] \\
& - \frac{e^{-y} E_\varphi}{p-2} \left\{ \left[\frac{E_\varphi}{(s+1)\epsilon} \right]^{p-2} \frac{y^{s+1}}{\underline{|s+1}} \right. \\
& \left. + \left[\frac{E_\varphi}{(s+2)\epsilon} \right]^{p-2} \frac{y^{s+2}}{\underline{|s+2}} + \cdots \right\} \Bigg\}.
\end{aligned}
\tag{24}
$$

It will be observed that the last part of this expression involving y^{s+1} and higher powers of y is independent of E_φ and therefore is unaffected by latitude, while the earlier forms experience a latitude effect. With increasing y, the responsibility becomes handed on more and more to the latter class, so that the latitude effect diminishes with depth of penetration.

Put $p = 3$

$$
\begin{aligned}
W = \frac{A}{2E_\varphi^2} \Bigg\{ & 2(1 - e^{-y}) E_\varphi - e^{-y} \Big[(2E_\varphi - \epsilon) y \\
& + (2E_\varphi - 2\epsilon) \frac{y^2}{\underline{|2}} \cdots (2E_\varphi - s\epsilon) \frac{y^s}{\underline{|s}} \Big] \\
& - e^{-y} E_\varphi \Big[\left(\frac{E_\varphi}{(s+1)\epsilon} \right) \frac{y^{s+1}}{\underline{|s+1}} \\
& + \frac{E_\varphi}{(s+2)\epsilon} \frac{y^{s+2}}{\underline{|s+2}} + \cdots \Big] \Bigg\},
\end{aligned}
\tag{25}
$$

$$W = \frac{A}{2E_\varphi}\left\{2(1 - e^{-y}) - e^{-y}\left[\left(2 - \frac{\epsilon}{E_\varphi}\right)y + \left(2 - \frac{2\epsilon}{E_\varphi}\right)\frac{y^2}{\underline{|2}} \cdots \left(2 - \frac{s\epsilon}{E_\varphi}\right)\frac{y^s}{\underline{|s}}\right] - e^{-y}\left[\frac{E_\varphi}{(s+1)\epsilon}\frac{y^{s+1}}{\underline{|s+1}} + \frac{E_\varphi}{(s+2)\epsilon}\frac{y^{s+2}}{\underline{|s+2}} + \cdots\right]\right\}. \tag{26}$$

Let us suppose that $s = 1$, and that, in fact, $E_\varphi = \epsilon$;

$$W = \frac{A}{2E_\varphi}\left[2(1 - e^{-y}) - ye^{-y} - \frac{y^2}{\underline{|2}}e^{-y} - \frac{y^3}{\underline{|3}}e^{-y} \cdots\right], \tag{27}$$

$$W = \frac{A}{E_\varphi} - \frac{A}{2E_\varphi}e^{-y}\left[2 + y + \frac{y^2}{\underline{|2}} + \frac{y^3}{\underline{|3}} \cdots\right], \tag{28}$$

$$\frac{dW}{dx} = \frac{A\beta}{2E_\varphi}\left[2e^{-y} + y_{10} + \tfrac{1}{2}y_{21} + \tfrac{1}{3}y_{32} + \cdots\right], \tag{29}$$

where

$$y_{mn} = \left(\frac{y^m}{\underline{|m}} - \frac{y^n}{\underline{|n}}\right)e^{-y}.$$

With this value inserted in (15) we may now plot n against x for a given E_φ if β is assigned. A maximum of n occurs for a value of x which depends upon β. Fig. 10 shows plots in the neighborhood of this maximum for different values of β[22]. It will be seen that the maximum occurs at a depth which is smaller, the larger β. Our arbitrary choice $\epsilon = 6 \times 10^9$ e.v., makes our condition $E_\varphi = \epsilon$ applicable at 42° magnetic latitude, and here the maximum occurs at $x = 0.75$, which is consistent with observations.[3] If we choose a larger ϵ, the latitude when E_φ will be equal to ϵ will be smaller, and we can afford to choose a smaller β.

[22] Different scales of ordinates have been taken for the different β's, the unit being inversely proportional to β. What has actually been plotted is the coefficient of $A\beta/2E_\varphi$ in the expression for n.

If, following the choice $\epsilon = 6 \times 10^9$ for constructing the curve for n versus x for the equator, we must use $s = 3$ in (26), and under these conditions, with $E_\varphi' = 18 \times 10^9$, we obtain for dW/dx

$$\frac{dW}{dx} = \frac{A\beta}{2E_\varphi}\left[2e^{-v} + 1.667\, y_{10} + 1.334\, y_{21} + y_{32} + \frac{3}{4} y_{43} + \frac{3}{5} y_{54} + \frac{3}{6} y_{65} + \cdots \right].$$

FIG. 10.

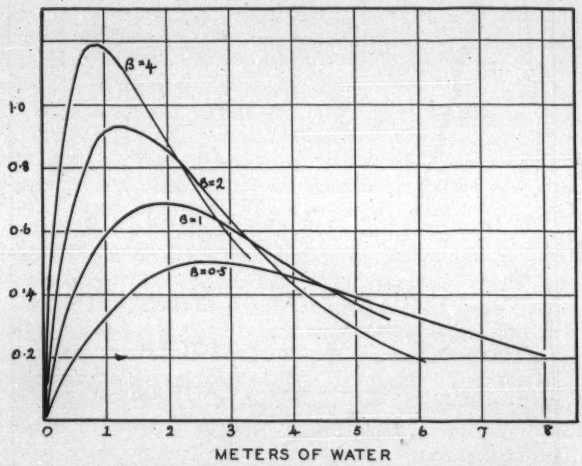
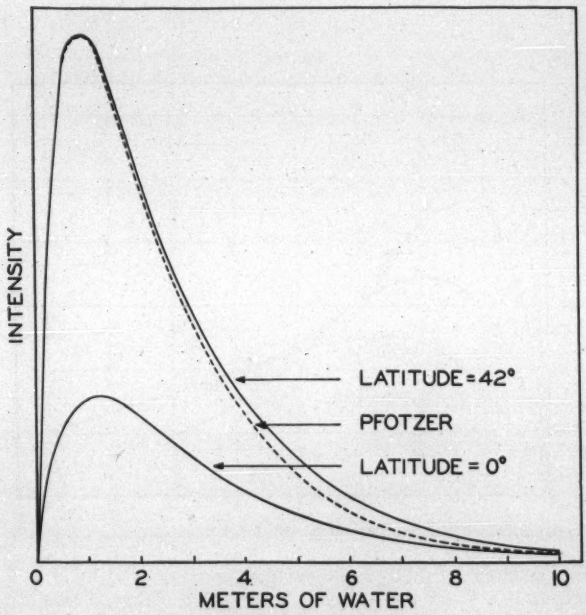


Fig. 11 shows n plotted against x for $\varphi = 42°$ and for $\varphi = 0$, and with $\beta = 4$ for both cases. It will be observed that the latitude ratio at the maximum is 2.5 to one. Moreover, it will be observed that the maximum occurs at a greater depth for the equator than for 42°. Both of these results are qualitatively in harmony with experiment.[3] It is not maintained that the choice of the various constants to fit the experimental facts within the limits of experimental error is necessarily unique. The dotted curve represents Pfotzer's experimental

data which are, moreover, harmonious with the Bartol Foundation's experimental data obtained in stratosphere and airplane flights.

At the points of maximum slope, the curves for 42° and the equator give absorption coefficients 0.5 and 0.27, respectively. We shall presently show that at great depths

FIG. 11.



$n = (\beta\epsilon/\eta)N$, where N is the intensity of the primaries, so that all the curves ultimately approach at great depths the same form as that for the primaries, a form which at these depths shows no latitude effect and which is dependent entirely upon the energy distribution in the primaries and is given by (13) on writing $\beta\epsilon$ for γ.

It is of interest to trace qualitatively the mathematical history of the development of the n versus x curve. In the first place, a group of secondaries, if left to themselves, without further replenishment, will of necessity conform to (14) with the right hand side equal to zero. They will, therefore, proceed with exponential absorption, with absorption coefficient $\mu_s = \alpha/\eta = 0.5$. Now starting from the top of the atmosphere, if β were very large, an enormous number of secondaries would be produced very near the top of the atmosphere [23] as in the quantum theory process, and these at lower depths would proceed according to their own law of absorption (the law (14) with the right hand zero) and with $\mu_s = 0.5$. The story some distance below the top of the atmosphere would be interfered with by the primaries to very little extent because very few of them would be left.

With a smaller β, but one larger than 0.5, the $\mu_s = 0.5$ characteristic of the secondaries alone strives to dominate the situation. It has, of course, to wait until the maximum has been attained. Then it does its best to establish itself—modified by β to some extent. Then as we go to greater and greater depths, β loses its influence in determining the law of absorption of the primaries, which then becomes determined entirely by the energy distribution law. The absorption coefficient so determined is one much smaller than μ_s, so that the secondaries following along in equilibrium with the primaries fail to exhibit their own coefficient of absorption and masquerade with the absorption coefficient of the primaries.

It may be well to make a comment concerning the large values of β which seem to be involved. With $\beta = 4$ and $\epsilon = 6 \times 10^9$, we have a condition in which the ray loses on the average 2.4×10^{10} e.v. per meter of water equivalent. It is to be remembered, however, that the larger ϵ and β, the larger the number of secondaries, so that in actuality the observation of a true primary may be a comparatively rare event. One advantage attending a large value of ϵ and β lies in the fact that such a condition provides for the very large showers found occasionally in lead.

Some of these matters will be clearer from the section immediately to follow.

[23] Of course, the number always grows from zero at the absolute top of the homogeneous atmosphere.

The Conditions for Great Depths—Number of Secondaries Accompanying a Primary, and Average Energy of the Rays.—As already stated, for large values of x the primary intensity passes over to the form given by (13), which, as may be seen from (6) by replacement of γ by $\beta\epsilon$, becomes

$$N_x = \frac{A}{(p-1)(\beta\epsilon x)^{p-1}}. \tag{30}$$

At these great depths the average loss per ray per unit of path is $\beta\epsilon$, so that

$$\frac{dW}{dx} = \frac{A\beta\epsilon}{(p-1)(\beta\epsilon x)^{p-1}}.$$

Inserting the value in (15) and integrating, we obtain, on the assumption that $n = 0$ at $x = \infty$ and on writing $(\alpha/\eta) = \mu_s$

$$n = \frac{A\beta\epsilon\mu_s^{p-1}}{\eta(p-1)(\beta\epsilon)^{p-1}}\left[\frac{1}{(\mu_s x)^{p-1}} + \frac{p-1}{(\mu_s x)^{p}} + \frac{(p-1)p}{(\mu_s x)^{p+1}} + \cdots\right].$$

At sufficiently large depths the series approximate to a form in which only the first term is important, and then, in view of (30), we have

$$n = \beta\frac{\epsilon}{\eta}N_x. \tag{31}$$

In the example we have studied, $\epsilon = 6 \times 10^9$. Since $\eta = 2 \times 10^8$, we have for the case $\beta = 4$,

$$n = 120\, N_x.$$

In other words, there would be 120 secondaries accompanying a primary.

In accordance with (7), the average energy of the primaries at great depths is

$$E_x = \frac{\beta\epsilon x}{p-2}.$$

Now (14) may be written

$$\frac{1}{n}\frac{dn}{dx} + \frac{\alpha}{\eta} = \frac{\beta\epsilon}{\eta n}, \tag{32}$$

so that since $(1/n)(dn/dx)$ is the coefficient for the secondaries and so, in view of (31), of the primaries at great depths, it is

to a first approximation negligible compared with α/η, which is 0.5. Hence (32) may be written

$$\alpha n = \beta\epsilon. \tag{33}$$

Now if $\bar{E}_x$ is the average energy of a primary, we have for the average energy of all the rays

$$\bar{E} = \frac{\bar{E}_x + n\eta}{n + 1}. \tag{34}$$

Hence, from (33) and (7), and neglecting unity compared with n

$$\bar{E} = \frac{\eta n}{n + 1} = \frac{\beta\epsilon x\alpha}{(p - 2)\beta\epsilon} = \frac{\alpha x}{p - 2}.$$

Hence, the average energy of all the rays bears a linear relation to x, as found experimentally by Dr. and Mrs. Montgomery, and the coefficient of increase, $\alpha/(p - 2)$, is equal to the experimental value 2×10^8 e.v. per meter of water equivalent for $p = 3$.

We have seen that a value of $\beta = 4$ gives 120 secondaries per primary, and even $\beta = 1$ gives 30 secondaries. Now our experiments cited earlier, in which we came to the conclusion that each penetrating ray was accompanied on the average by only 0.6 electron rays, presents a difficulty until one admits that most of the penetrating rays may also be secondaries, a conclusion which has been advanced from other considerations.[12] Thus, for example, our mine experiments would be in harmony with the view that the true primaries are negligible in relative number as in the above considerations, but that of every 16 secondary rays, 10 are penetrating rays, and 6 electrons.

It will be observed that according to the views here presented, the phenomena of the so-called hard and soft components are phenomena of a single primary component which itself comes into direct evidence only in minor degree, being represented by secondaries in all of its activities usually associated with a hard and soft component. It may itself show its individuality by its occasional power to produce large numbers of secondaries in small distances, the extent of this power and also its rareness of action depending upon β and ϵ.

It is not the purpose of this paper to account for the phenomena postulated for the primary—its property of producing secondaries with a probability independent of its energy—for cosmic-ray energies at least. This is a matter for a different type of theoretical treatment. In so far as one is tempted to invoke existing particles, however, one is tempted to think of of protons. As a matter of fact, protons have been suggested from time to time,[24] particularly as representatives of the hard component, and of course without the properties here required.

ORIGIN OF COSMIC-RAYS.

The story of the origin of cosmic-rays is too large to be treated adequately as part of a lecture which has been so much concerned with other matters. Professor Compton has given us cogent reasons for supposing that they come from our galaxy. Elsewhere,[25] I have shown that the existence in interstellar space of cosmic-rays of one sign in number sufficient to supply the measured intensity, would give rise to prohibitively high electric differences of potential differences of the order of 10^{17} volts between points a light year apart. Hence it becomes necessary to suppose the positive rays neutralized by a negative space charge in interstellar space. Gunn [26] has offered an ingenious suggestion to provide for an emission of heavy particles and light particles from stars under conditions in which both kinds attain the same average velocity. Then the earth's magnetic field acts as a barrier to the particles of low rest mass, admitting the others. With the assumption that the heavy particles are positively charged, the positive sign of the incoming primary rays is thus accounted for.

In the discussion of Professor Compton's paper given at this symposium, I pointed out that magnetic fields of the order of magnitude of those calculated by Alfven for the galaxies would result in the existence of electric fields in the frame of reference of one in respect to whom the galaxy was in motion. To such an observer, in fact, the moving galaxy acts as an

[24] A. H. Compton and H. Bethe, *Nature*, 134, 734 (1934); also A. H. Compton, *Rev. Sci. Inst.*, 7, 71 (1936); also T. H. Johnson, *Phys. Rev.*, 45, 569 (1934).

[25] W. F. G. Swann, *Phys. Rev.*, 44, 124 (1933).

[26] R. Gunn, *Terr. Mag.*, 38, 247 (1933).

electric as well as a magnetic doublet. Now, of course, there is always motion of some of the galaxies relative to any fixed point; and for a relative motion of one tenth the velocity of light, I calculate that potential differences of the order of 10^{22} volts can arise between infinity and points at distances from the galaxy comparable with its dimensions. This is for a galaxy where the magnetic field is 0.1 gauss at the center. Professor Compton has given cogent reasons to support the view that magnetic fields of this order would be inconsistent with the observed facts. However, one can afford to have a magnetic field of amount quite negligible compared with this, and yet obtain enormous potentials. Of course, these energies would not have reality for one who occupied the moving galaxy, since in the frame of reference of the galaxy there is only a magnetic field, and that can give no energy to a particle. However, calling the galaxy A, then to another observer in a relatively moving galaxy B, a charged particle shot out from an appropriate place in A to infinity would, in general, acquire those energies which would appear as realities to the observer in B, provided only that the particle could get to infinity. Here, however, the magnetic field would step in to defeat the endeavor of the particle to leave the galaxy.

In further connection with the discussion of Professor Compton's paper, I have shown that galaxies carrying fields of the order 0.1 gauss would have the ability to attract or repel one another to such extent as would give two galaxies a relative velocity of the order one tenth that of light in periods of the order 10^5 years.

Concerning other methods of acquiring cosmic-ray energies, I pointed out several years ago [27] how it is possible to provide for such energies through the operation of electromagnetic induction resulting from fluctuating magnetic fields in stars. Fields fluctuating at the rate comparable with the rates observed in sunspots can, if spread over a sufficiently large area in a star, give rise to energies of the order 10^{10} e.v. without the absolute magnitudes of the fields being anything like those comparable with the observed fields in sunspots.

There is always open the possibility suggested by terrestrial thunderstorms. When we observe that a terrestrial thunder-

[27] W. F. G. Swann, *Phys. Rev.*, **43**, 217 (1933).

storm can give rise to potential differences of the order of 10^9 volts, and when we recall that a thunderstorm is nothing more than a huge electrostatic machine operating under the influence of gravity, it would not be unreasonable to contemplate phenomena of the character of "stellar thunderstorms" which could give rise to energies comparable with much more than 10^9 e.v.

It might be argued that since many electrostatic machine charges of equal and opposite sign are produced, the potential difference to infinity would be zero. This is not the case, however. For imagine a sphere of radius a charged with Q units, and with the opposite charge on the surface beneath, at a distance r. To a first approximation, the field will be that of the sphere, and an oppositely charged "image" sphere located at a distance r below the surface, and a charge $-Q$ at the center of the star, which we shall suppose of radius R. The potential of the sphere in relation to infinity is, therefore, of the order V_1 where

$$V_1 = Q\left[\frac{1}{a} + \frac{1}{R+r} - \frac{1}{2r}\right].$$

The potential difference between the sphere and the surface of the star, which is the potential difference of the "stellar thunderstorm" is of the order V_2 where

$$V_2 = Q\left[\frac{1}{a} - \frac{1}{2r} + \frac{1}{R+r} - \frac{1}{R}\right].$$

Hence, V_1 and V_2 are of the same order, and the potential differences observed between the charged "cloud" in the star and the star itself is comparable with the potential difference from the "cloud" to infinity.

Some years ago [28] I pointed out that if the stars possessed electric fields of an amount comparable with the earth's electric field, or even less, and provided that these fields extended out to infinity, which, however, the earth's *surface* field does not do, then galaxies might acquire very large potential differences. Thus, with a surface field equal to that of the earth, but extending out to infinity, the sun's surface would have a potential of 6×10^{10} volts. If we consider a galaxy in the form of a

[28] W. F. G. Swann, *Phys. Rev.*, **42**, 914 (1932).

flat disc of radius R containing N stars, each of radius a and surface field X, the potential at the center of the galaxy is easily shown to be

$$V = 2\frac{Na^2X}{R} \text{ volts, if } X \text{ is in volts per cm.}$$

If $N = 10^9$ stars, as for our galaxy, and a corresponds to the sun's radius,

$$V = \frac{7 \times 10^{30}}{R} X.$$

The radius of our galaxy is 5×10^{22} cms. Hence, a surface field of 100 volts per cm. would give a potential of 1.4×10^{10} volts within the galaxy. Of course, the surface field *at* one of the stars would be much larger. It would, in fact, be 6×10^{12} volts.

Finally I may refer to a method of realizing cosmic-ray energies which I suggested in 1934,[29] and founded upon an earlier theory in which I showed [30] that it was possible to make a self-consistent modification of the electrodynamical equations in such manner as to provide for a continual death of positive electricity and so account for the maintenance of the earth's electric charge and the atmospheric electric current.

If we imagine a continual outward flow of current i from a region, a space charge will result which by self-repulsion will provide for the particles attaining a velocity approximately that of light in distances of no great amount compared with the distances which will be concerned.

Through a sphere, therefore, of radius r, we picture a current flowing with velocity c. The density ρ will be

$$\rho = \frac{i}{4\pi r^2 c}.$$

The total charge within the sphere will be of the order Q, where

$$Q = \frac{4}{3}\pi r^3 \rho = \frac{ir}{3c}.$$

[29] W. F. G. Swann, *Phys. Rev.*, **45**, 295 (1934).
[30] W. F. G. Swann, *Phil. Mag.*, S. 7, vol. 3, 1088 (1927).

The field at any distance r will, therefore, be of the order

$$X = \frac{i}{3\sigma r}$$

and the potential difference between any place at a distance r_0 from the center and another place at a great distance R is

$$V = \frac{i}{3\sigma} \log \frac{R}{r_0}.$$

This approaches infinity with infinite R. For a value of i equal to the atmospheric current ($i = 1000$ amperes), we have $V = 10^4 \log_e R/r_0$. If from a galaxy there was as much current flowing out as would correspond to only 10^6 times that from the earth, we could realize a condition in which $V = 10^{10}$ volts with R comparable with r_0. Although R can in ideality become infinite, even if $R/r_0 = 10^9$, V would be only 30 times the value for $R/r_0 = 2$; and if r_0 were comparable with the radius of a galaxy (50,000 light years), an R giving $R/r_0 = 10^9$ would correspond to 5×10^{13} light years, and this time would have to elapse before the density had established itself at the distance R, so that even the magnitudes available in astronomical times do not provide for drawing upon the approach of $\log_e R/r_0$ to an infinite value. In spite of the rather artificial nature of the premises, however, the order of magnitude of the potentials capable of arising in the foregoing manner merits some consideration.

NOTES ON CELLOPHANE.

BY

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Cresson Medalist.

Solutions of cellulose began at the close of the 19th century to find important applications for the manufacture of artificial textiles. Rayon was developed rapidly and at the beginning of the 20th century this industry was already very active. Viscose silk, especially, which is prepared from sodium xanthate solutions of cellulose discovered by Cross, Bevan and Beadle in 1892, had during 1908–1910 already attained considerable importance.

On the other hand, the manufacture of regenerated cellulose film from its solutions had not shown appreciable progress before 1908. Cross had prepared in his laboratory at the beginning of his researches on viscose cellulose films of small area, and numerous inventors had seen the possibility of manufacturing these films, but as a matter of fact, no industrial solution of the problem had been achieved.

If I succeeded between 1908 and 1911 in establishing a process and a machine which furnished a practical and economical solution to the problem, I believe I can attribute it to the two following considerations:

The first is that I had specialized for many years in the bleaching industry, in dyeing and stamping cotton tissues, which had made me familiar with the technic of continuous cellulose tissue processes.

The second circumstance resulted from my having invented a machine to mercerize cotton tissues, based on a new principle and on which I had solved, satisfactorily, the problems which have to do with tension and the tendency to shrink that these tissues undergo in the course of different operations. I had succeeded in acquiring, under these conditions, a thorough knowledge of machines used in the treatment of cellulose

tissues and the problem of the continuous manufacture of Cellophane confronted me with similar conditions.

I shall not give a detailed treatise on the manufacture of Cellophane, which is very well described in several technical works and which has scarcely been modified, so far as underlying principle is concerned, since its beginning. I shall merely touch upon the fundamentals.

Viscose brought to an advanced degree of maturity is sent, in the form of a liquid nappe of 1.8 meters and larger and of several tenths of a millimeter in thickness, into a coagulating bath which solidifies it. It undergoes a treatment which renders it insoluble in water, followed by a desulphuration in boiling soda, and a bleaching, and, then, a dyeing and an impregnation with glycerine, and finally a drying,—these operations being interspersed by copious washings in water, the operations being carried out continuously on a single machine seventy meters long. The travel of the film in the machine is several hundreds of meters and the speed used is now up to sixty meters per minute. The liquid viscose nappe, which constitutes the beginning of the film in the machine, must be controlled very accurately and calls for a slit adjustable by hundredths of a millimeter in all directions and made of resistant alloys. The opening of this slit of course decreases from the center to the sides following a law taking into account the spread.

The regenerated cellulose film, in passing through the machine and, particularly, in passing through the dryer, is submitted to very different tensions, longitudinally and laterally, of such a nature that the Cellophane presents birefringence qualities which are very marked, readily showing distinct chromatic polarization.

The physical properties of Cellophane are very interesting and are susceptible of giving to this material a great variety of possible applications.

Cellophane swells under the influence of water and absorbs approximately 85 per cent. of its weight of this liquid. If Cellophane is dried by saturated vapor under a pressure of 2 kgs. for several hours, it is altered and can no longer absorb more than 35 to 40 per cent. of its weight of water.

In an atmosphere of 60 per cent. saturated with water vapor, Cellophane retains approximately 9 per cent. of water. I frequently ask myself what could be the physical state of the water contained in Cellophane, which is more or less moist, when it is rapidly cooled. At what moment does the water change to the solid state? What internal pressure supports it at that moment? Does it remain in a state of surfusion?

Cellophane is easily impregnated with saline solutions and after drying maintains its transparency with a fairly large number of salts. For example, such is the case with a solution of chloride or bromide of ammonium or of nitrate of lead. If the quantity of hygroscopic water and glycerine contained in a Cellophane thus dried is too weak to carry the salts in a condition of solution, the question arises in what form do the solid salts contained in the mass exist and how may they be oriented. It would be, in my opinion, interesting to study this question from the point of view of the X-ray spectrum. The incorporated salts seem to modify the properties of the film. Ammonium chloride and bromide have made it fireproof and rendered it incombustible. Nitrate of lead, on the contrary, permits it to burn without flame by simply igniting one of its corners.

If to one type of cellulose impregnated with a saline solution, there be added another saline solution having a higher molecular concentration than the first, there result deposits of insoluble salts having varying properties. In this manner a film can be prepared containing barium sulphate which is entirely transparent, one with sulphate of lead will be opalescent, with chloride or chromate of lead opaque. With the halogen salts of silver a chloride or bromide of silver is readily obtained, at first transparent, then opalescent which, in the presence of a soluble halide in excess, progressively swells and becomes more and more opaque. Cellophane prepared in this manner furnishes photographic film which is especially remarkable, reminding one of the collodion processes.

I would further mention as particularly interesting the action of gases such as hydrogen sulphide or iodine vapor on a Cellophane dry or moist impregnated with certain salts such as silver nitrate. There are thus produced beautiful deposits of silver sulphide or iodide having a metallic appearance.

Cellophane can render distinct service for ultrafiltration for processes in which osmosis enters into play, and I am convinced that it will permit of the preparation of semi-permeable membranes which will have remarkable qualities.

Thanks to its aptitude in absorbing water, Cellophane does not cloud over with mist and this property has lead to its use on a large scale in the manufacture of eye-pieces for gas masks.

Cellophane presents a certain permeability to gases, but this permeability operates in favor of the water vapor which it contains and which serves as a vehicle for the gas through its solution in this water. Hydrogen, which is but slightly soluble in water, diffuses very slowly so that small balloons of Cellophane filled with hydrogen are capable of retaining the gas longer than those made of rubber.

Cellophane, which is very permeable to aqueous liquids, is, on the contrary, absolutely impermeable to organic liquids insoluble in water, such as oil, gasoline, benzol, and this property has permitted of its use in forming an impermeable membrane of pipes used in conveying gasoline. This impermeability is not, however, absolute for liquids miscible with water, such as alcohol, for, as in the case of gases, the water held in the Cellophane aids in their diffusion.

Cellophane has found many important uses in the United States thanks to the researches of the du Pont de Nemours Company which has succeeded in imparting to it a remarkable impermeability to water vapor. The process consisted of applying on both sides of the film a layer of from one to two microns in thickness of a varnish made by a mixture of a cellulose derivative, a resin, a plastic and a wax which does not in any respect modify the appearance or the feel of the Cellophane.

Under these circumstances, its permeability to aqueous vapor is 300 times less than that of the original film, so that products packed in containers manufactured with this moisture-proof Cellophane are scarcely affected by the hydroscopic changes in the atmosphere.

Besides the vast field of wrappings for all sorts of products, I would mention some applications of Cellophane which are but little known. For example, the manufacture of sausage casings, for Cellophane sticks to itself easily by using concen-

trated zinc chloride solutions, which cause a superficial dissolution. I may mention numerous fantasies of fashion which make use of Cellophane in many varied ways, such as in different colors, or mottled, metallized, mat, iridescent, printed, alone or associated with other textiles, in wide ribbons or in very narrow ribbons two-tenths of a millimeter in width, in tubes like straw and as paillettes.

Cellophane in continuous rolls is an ideal substance for the mechanical recording of music or the voice, with the assistance of a simple pick-up.

It lends itself equally well to numerous photographic and cinematographic applications, particularly when sensitized with a mixture of a diazo compound and of a phenol and developed simply through the action of ammonia gas. Its application to microphotography, which is developing so rapidly in the United States, will find its place as an ideal material in "Ozaphane" film. This same material, in the form of ribbons, a few millimeters in width and several hundredths of a millimeter thick, is used to carry photo-sound tracks which are reproduced by a photoelectric cell operating a loud speaker. The apparatus is of small size and weight and one continuous film can run for a very long time. It is probable that on this material the books and the newspapers of the future will be printed. The cold characters which now must interpret our feelings will be replaced by a modulated voice which, intensified by the charm of the spoken word, will create the impressions in our imaginations.

As I hesitate to fall into the domain of mere publicity, I prefer to stop at this point and to content myself with concluding with an expression of my admiration of that magnificent country the United States where Cellophane has found such rapid development, thanks to the inexhaustible research and ingenuity of its citizens.

Shall Grand Coulee and Bonneville Send Power to New York?—(*Power Plant Engineering*, Vol. XLII, No. 9.) A scheme as daring in conception as was Marconi's plan to first send wireless signals across the Atlantic, is that of J. D. Ross, Administrator of the Bonneville federal hydroelectric project. The plan was presented in an address before the Engineers' Club of Seattle recently and it suggests linking the northwest hydro plants with eastern and middle western centers of population by means of transmission lines up to 3000 miles in length, extending from ocean to ocean and with ties from Canada to Mexico. Despite its startling and staggering proportions, his proposed transmission system is based on sound reasoning and on developments which if at present incomplete, give promise of success in the comparatively near future. It is proposed to use direct current for transmission and is therefore dependent upon the further development of apparatus to convert high voltage alternating current to direct and vice versa, specifically upon electron tube rectifiers and inverters. Such equipment for 50 to 150 kilovolts is available today but much higher voltage equipment is necessary. Mr. Ross computed the cost per kwh. of a line from the Columbia River to Chicago and N. Y. at 400 kv. per wire, and with a loss of only 10 per cent. Two such wires of 2,500,000 cir. mill copper, one negative and one positive to ground, would transmit to Chicago 760,000 kw. at a cost of about one mill per kwh. for transmission only, assuming an 80 per cent. load factor. If the voltage were raised to 750 kv. there could be delivered to N. Y. 1,800,000 kw. on the present N. Y. load factor of 50 per cent. with a cost of less than 1 mill per kwh.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

FIRE RESISTANCE OF WOOD-STUD PARTITIONS FILLED WITH MINERAL WOOL.

Several wood-framed partitions with the space between the studs and the facings filled with mineral wool have been included in a current series of fire tests in an effort to increase the fire resistance without change in the material or thickness of the facings. The constructions were built into moveable frames and, for the fire test, were placed to form one wall of the furnace chamber. The tests were conducted in substantial accord with specifications developed under the auspices of several national technical societies and this Bureau (see American Standards Association Standard A-2-1934, and American Society for Testing Materials Standard C19-33). Most of the partitions were tested under load in fire endurance tests. Fire and hose stream tests were conducted with constructions that withstood the fire endurance test for one hour or more, and had been found to pass the requirements in this respect.

A summary of the results is given in the table, in which the fire resistance periods are given for ¼ hour intervals. For the bearing classification the results are based on ability to sustain for the given period under the fire exposure a design load, taken as 358 lb./in.^{2} of net area of wood studs, the occurrence of an average temperature rise on the side not exposed to fire of 250° F. or a rise at any point of 325° F., passage of flame, or ignition of cotton waste placed against the unexposed side. For the nonbearing classification all but the first of these criteria are applied.

In the first two tests listed, the loose rock wool was dropped into the stud space in a height of 4 ft. and tamped with a sash weight in the case of the first test, and lightly packed with a stick for the second. Both failed through ignition of boards on the unexposed side at points where there were voids in the

* Communicated by the Director.

fill, the results differing little from those obtained with a similar unfilled partition. In the third test the fill was placed progressively as the facing was applied, resulting in a fill of more uniform density.

For the partition faced with lime plaster on wood lath, the fill was placed by pneumatic means after the partition was

RESULTS OF FIRE TESTS OF WOOD-STUD PARTITIONS FILLED WITH MINERAL WOOL.

Facings			Filling		Fire endurance period	
Material	Thickness of plaster or board	Plaster mix	Form	Density	Bearing	Nonbearing
	inch			*lb./in.*^{3}	*hr.*	*hr.*
T. & G. 3-in. wood ceiling boards	¾	—	Bulk, tamped	6.9	¼	¼
Do	¾	—	Bulk, loose	2.7	¼	¼
Do	¾	—	Bulk, hand packed	2.6	½	½
Wood lath, lime plaster	½	1 : 5 1 : 7½	Pellets blown in	2.2	—	¾
Gypsum board	½	—	Bats, not nailed packed	0.6 to 1.2	¾	1
Do	½	—	Bats, nailed	.6 to 1.2	1	1
Wood lath, gypsum plaster	½	1 : 2 1 : 3	Bats, not nailed	1.0 to 1.3	1¼	1¼
Do	½	1 : 2 1 : 3	Bats, nailed	1.0 to 1.3	1¼	1¼
Metal lath, gypsum plaster	¾	1 : 2	Bats, ⅔ nailed	1.0 to 1.3	1½	1½
Do	¾	1 : 1	Bats ⅔ nailed	1.0 to 1.3	1½	1½

built and aged, the equipment used being typical of those applied in placing wall and attic insulations. The failure in this case was also apparently at a void or sparsely filled location in the fill. The partition, however, withstood the test for 16 min. longer than a similar unfilled partition. Some further tests with wood lath and plaster partitions with mineral wool fill in bat form are in progress.

The mineral and glass wool bats applied as fill in the remaining tests were of the usual wall-thick types used for house insulation, with waterproofed paper on one side. They were 15 in. wide and 23 to 48 in. long, and were placed against one facing for the full height of the partition before the other facing was applied. Where secured by nailing, 8d finishing nails were driven on 12 in. centers through both ends of the bats into the middle of the sides of the studs. The densities given apply for the nominal area of the bats. As compressed into the stud space the density would be about 10 per cent. higher, or equivalent to about 2.2 lb./ft.^{3} for glass wool and 3.6 to 4.7 lb./ft.^{3} for mineral wool.

The filling increased the fire resistance of the construction with the ½ in. gypsum board facing by 10 to 20 min., for that of gypsum plaster on wood lath by 25 to 30 min., and for those of gypsum plaster on metal lath by about 30 min. The proportions given in the table for the plaster mix are in terms of weight of gypsum plaster or dry hydrated lime to dry weight of sand. Where two ratios are given, the first is for the scratch coat and the other for the brown coat. The Potomac River sand used has a high content of quartz and chert. Where a white finish was applied, its thickness is included in the given thickness of facing.

The tests indicate that the filling of wood-stud partitions results in a substantial increase in fire resistance. The filling apparently retards the transmission of heat to the unexposed facing and decreases the rate of burning of the wood supports. The results indicate that care is needed to obtain a fill without voids. Apparently this condition is more often attained with fills in bat form placed before the last facing is applied than with fills placed after both facings are in place. The former method also affords opportunity for inspection. However, even with this type of construction care must be exercised if results comparable to the ones given here are to be obtained. The truth of this is brought out in cases where the facing on the side exposed to fire disintegrates or falls off relatively early in the test. Then, if the filling has been nailed in place, or held by equivalent means, added fire resistance is obtained. This is true to a less extent even if the facing does not fall off.

EFFLORESCENCE OF BRICKS.

It is known that efflorescence on brick masonry may originate from the bricks or mortar, or both. It is also known that the soluble salts in bricks may originate from the raw materials (clay or shale), water, or from kiln gases. Observations in various communities in the United States show that in some the walls are practically free from observable efflorescence, while in other cities much is visible. On the assumption that some of these differences are related to differences in bricks, a statistical study was made of data accumulated in 1930 as part of a survey of properties of building brick produced in the United States. The data obtained included liability to efflorescence as measured by the 5-day wick test (*J. Research N. B. S.*, **19**, 105; July, 1937 (RP1015)), strength, water absorption, saturation coefficient (ratio of absorption by cold immersion to absorption by boiling), kind of raw material (clay, shale, or fire clay), method of forming (dry press, soft mud, side cut, and end cut), rating by manufacturers as to degree of firing ("hard" or "salmon"), and geographical location. A study of 638 samples from 219 manufacturers gave the following conclusions:

(1) Liability to efflorescence is less for hard-fired brick than for under-fired brick if strength, absorption, and saturation coefficient are considered as measures of degree of firing.

(2) No significant difference in tendency to efflorescence is found when bricks made from different raw materials, clay, shale, and fire clay, are compared.

(3) No effect of method of forming (dry press, soft mud, side cut, and end cut) on tendency to efflorescence was observed.

(4) The weighted distribution of the data for 638 samples from 219 plants is as follows: 85.0 per cent. less than "moderate," 10.9 per cent. "moderate," and 4.1 per cent. exceeding "moderate," on the scale for tendency to efflorescence as measured by the 5-day wick test.

(5) The corresponding weighted values for the samples classified by the manufacturers as "hard" (94.1 per cent. of total) are 86.0 per cent. less than "moderate," 10.4 per cent. "moderate," and 3.6 per cent. greater than "moderate."

(6) The weighted distributions for the samples classified by the manufacturers as "salmon" (5.9 per cent. of the total) are 67.8 per cent. less than "moderate," 19.0 per cent. "moderate," and 13.2 per cent. exceeding "moderate."

FIBER INSULATING LATH AS A PLASTER BASE.

Among the modern building materials which appeal to many for house construction are the numerous types of wall, insulating, and plaster boards.

An investigation of the properties of these boards, with special reference to the suitability of fiber insulating lath as a plaster base, was completed recently at the Bureau, and a report on the work, Building Materials and Structures, BMS3, has just been released.

Such properties as density, strength (flexural and tensile), and linear changes accompanying changes in relative humidity and wetting and drying were studied. The boards were mounted on steel frames so that the extent of buckling resulting from changes in relative humidity could be measured. Methods of successful application of plaster on insulating lath were ascertained by experiments in which the thickness, sand content, strength, and time of set of the plasters were varied independently.

The following types of boards were investigated: Eight fiber insulating, 1 plywood, 2 gypsum, 1 cement-asbestos, and 1 compressed fiber.

The weight of the fiber insulating boards (½ inch thick) ranged from 699 to 1143 lb. per 1000 sq. ft. when measured at 65 per cent. relative humidity. The average flexural strengths of these boards at 80 and 100 per cent. relative humidity were about 20 and 50 per cent. lower, respectively, than at 40 per cent.

The expansions which accompanied a change in the relative humidity of the air from 25 to 90 per cent. ranged from about 0.07 per cent. for the gypsum boards and cement-asbestos board to about 0.47 per cent. for some of the fiber insulating boards, the range of the latter type being about 0.26 to 0.47 per cent. When the boards were kept at 100 per cent. relative humidity, or in water, the expansions were

from 25 to 95 per cent. greater than those obtained at 90 per cent. relative humidity. Painting the boards materially decreased the rate of expansion but did not eliminate it.

Boards attached rigidly along their edges to steel frames gave greater buckling (rise in hundredths of an inch, across a 16-inch span) than when the boards were less firmly attached. When firmly attached along the outside, the buckling of the boards ranged from 0.05 inch for the gypsum wall board to 0.54 inch for one of the fiber insulating boards when the relative humidity was increased from 35 to 90 per cent.

It was found that weak, oversanded plasters applied to the insulating lath were very unsatisfactory even when quick-setting and $\frac{5}{8}$ inches thick.

Strong, quick-setting plasters $\frac{5}{8}$ inch thick were satisfactory, but when the thickness was $\frac{3}{8}$ inch, cracks developed in some instances along the horizontal joints after the panels had been dried.

Copies of this report are obtainable from the Superintendent of Documents, Government Printing office, Washington, D. C., at 10 cents each.

RECORDS OF PRESENT CIVILIZATION PRESERVED IN "TIME CAPSULE."

Members of the Bureau's staff recently assisted in a most unusual venture, that of preparing a message for the civilization of the future, to be opened 5,000 years hence. The message is in the form of an 800-pound cupaloy "Time Capsule" which was deposited 50 feet below the surface of the New York Worlds Fair grounds by the Westinghouse Electric and Manufacturing Company, On September 23, 1938, with instructions that it is not to be opened before the year 6938. The capsule has sealed within it, in an atmosphere of nitrogen, records and articles portraying a cross section of our present-day civilization. Micro-film made it possible to pack a voluminous collection of records in a very small space, the four reels of film covering more than 100 volumes showing the scientific, engineering, industrial, social, religious, and philosophical achievements of our age. A "Book of Record of the Time Capsule," made to survive 5,000 years,

was designed and published for the occasion, and copies will be deposited in various libraries. It is an example of the finest modern craftsmanship, set in Goudy type, printed on permanent record paper, bound in royal blue buckram, and stamped in genuine gold. The book contains a message to posterity; a description of the contents of the capsule; detailed instructions for finding and raising the capsule; and a "Key to English" by Dr. John P. Harrington of the Smithsonian Institution. One copy was inclosed within the capsule, and other copies are to be preserved in libraries and other depositories throughout the world.

The paper used in the "Book of Record," the microfilm, the film cans, and the paper used to wrap separately the articles placed in the capsule were made in accordance with specifications furnished by the Bureau, which was also consulted on many other details. C. G. Weber of the Bureau's paper seciton was one of the three official witnesses of the packing and sealing of the capsule.

STRESSES IN A ROTATING PROPELLER BLADE.

A knowledge of the natural frequencies and of the stresses caused by resonant vibrations at those frequencies is important in designing propeller blades. Metal blades of modern design are amply strong to withstand the static stresses from air loads and centrifugal force. Examination of propellers, the failure of which resulted in airplane accidents, has in every case indicated the presence of vibration before failure. Vibration may set up high alternating stresses at certain critical speeds at which the frequency of a periodic exciting force in the propeller-engine assembly or in the airflow coincides with a natural frequency of the propeller. Probably the most important natural frequencies are those for which the propeller vibrates flexually like a beam of variable section. The determination of stresses in a non-rotating propeller vibrating in this manner was discussed in *J. Research N. B. S.*, **14**, 189 (February, 1935) (RP764). It was shown in this paper that the bending stresses in a propeller blade could be determined from strain measurements on the surface of the blade after the blade had been set into resonance with the

desired flexural mode. Both the stresses so determined and the observed frequencies were found to agree with those calculated from the theory of beams of variable section.

The results of tests or calculations on non-rotating blades can be applied to propellers in flight only if the effect of rotation on the natural modes of vibration is clearly understood. In RP1148 (November *Journal of Research*) Walter Ramberg and Sam Levy discuss this effect by extending the method of computing the natural modes of flexural vibration of non-rotating blades, described in RP764, to blades that rotate as in actual flight. The resulting equations were solved numerically for two aluminum alloy propeller blades of typical design vibrating with the fundamental mode (with a node near the hub) and with the second harmonic mode (with one node near the tip and the other near the hub), and rotating at service speeds. Rotation was found to have a small effect on the maximum stress per unit tip deflection and was found to shift the maximum toward the hub. For engineering calculations it is probably sufficient to calculate the resulting stress in the rotating blade by superimposing the stress for no rotation on the steady stress due to air loads and to centrifugal force. A close and convenient approximation to the natural frequencies, which are needed to determine the critical speeds, was obtained from Lord Rayleigh's method by making use of the solutions for no rotation outlined in RP764. It is shown that both the stress distribution and the natural frequencies of a given propeller blade may be derived from those measured for a model blade by making use of two simple model rules due to Theodorsen.

TESTS OF DOMESTIC GAS METERS.

Ordinary gas meters have been regarded with distrust by the general public almost since they were first used. While there may have been some justification for this attitude at first there is very little, if any, today. As a comparison, the water meters commonly used on residence service lines are required to register within $\pm$ 2 per cent. of the true amount over most of their range, while at very low rates may be incorrect by 10 per cent. or may not register at all. On the

other hand, many jurisdictions require that gas meters shall be correct within ± 1 per cent., and must register even the lowest rates of flow. Indeed, gas meters have been used to detect the presence of leaks in service piping! The public probably accepts water meter statements more readily than those from gas meters, because water usually costs much less than gas, and whereas water can be seen coming from a faucet so that one can visualize how much is used, gas is not visible as it issues from a stove burner.

To make more certain that, on the one hand, the user receives all the gas he pays for on the basis of the meter indication, and on the other that the gas company receives credit for all the gas the meter shows was delivered, the requirements of gas meter testing are rather exacting. In the District of Columbia, for example, no gas meter can be placed in service unless it has been tested and passed by or under the personal supervision of the gas inspector of the Public Utilities Commission. This official noticed that occasionally the Commission's test disagreed with the test made by the gas company by a small amount (less than 1 per cent.). To reduce these occasional differences to a minimum, the Commission, together with the chairman of the American Gas Association's Committee on Meters and Metering, sought the Bureau's coöperation in studying possible sources of difference in gas meter tests.

The first step in this study was to analyze and evaluate possible sources of errors. Next, tests were made on about 125 meters to compare different methods of using the index hands in making a test, and the relative abilities of several operators. Official tests of over 75 meters were observed and checked. Other tests were made of operator's abilities to stop a gas meter test hand at a desired position and to set and read gas meter prover scales. Some of the results of these tests may be summarized as follows:

1. There is no definite change in the condition or proof of a gas meter as indicated by the successive tests made in this study.

2. On the average, the operators stopped a meter test hand within 0.002 inch of the starting point, and rarely missed by as much as 0.01 inch.

3. The prover scales were set on zero at the start of a test to within less than 0.001 cu. ft., and the final reading was made to within 0.01 cu. ft.—usually less than this.

4. In reporting meter proofs there appeared to be a tendency to give the "benefit of the doubt" on the slow side in border line cases.

As a result of these tests, it was suggested that the positions of the meter provers and the meters be changed so that they might be observed by the operator with less possibility of error due to parallax: A new design of test hand for gas meters was offered.

The complete account of this study will be incorporated in the 1938 report of the Subcommittee on Meters and Metering, Distribution Committee, Technical Section of the American Gas Association.

THE FRANKLIN INSTITUTE

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Qualitative Organic Microanalysis.—HERBERT K. ALBER. (Microchemical Laboratory of the Biochemical Research Foundation of the Franklin Institute, Philadelphia, Pa.) Comprehensive schemes for the qualitative identification of organic compounds encountered in chemical and biochemical research have been proposed during recent years. Although microchemical techniques have frequently been employed in special cases, the schemes still rely on the use of ordinary macro methods. The application of micro techniques in qualitative organic analysis (following the macro schemes of Mulliken, Staudinger, Kamm, Shriner and Fuson) has been studied by the author during the past five years. Some of the results of these studies have been presented *; a complete report will be made in a series of forthcoming publications.

In investigations of so general a nature it is important to use simple methods, common reagents, and inexpensive equipment; to conserve material, avoiding the destruction of the substance during analysis whenever possible; to compare many substances with widely varying characteristics; to use compounds of commercial grade, rather than highly purified products, for testing the efficiency of the various procedures; and to select tests offering the possibility of semi-quantitative evaluation.

The first step in this comprehensive scheme is the separation and purification of the compound in question to such

* Pittsburgh Meeting, A. C. S., fall 1936 (viscosity); Rochester Meeting, A. C. S., fall 1937 (application of elementary analysis); Richmond Meeting, A. C. S., December 1937 (elementary analysis); Milwaukee Meeting, A. C. S., fall 1938 (specific gravity, microextraction).

Mikrochemie **21**, 142 (1936); Ibid., **23**, 235 (1937); Ibid., **24**, 97 (1938); Ibid., in press (1938) (preparative methods for hygroscopic liquids); Industrial Engineering Chemistry, Analytical Edition **10**, 47 (1938); Journal of the Franklin Institute **224**, 729 (1937); Ibid., **225**, 164 (1938).

extent that the determination of solubility and of the physical constants will give satisfactory values for a preliminary classification. The techniques best suited for solid compounds are recrystallization in centrifuge cones, capillaries, or on slides, and mechanical separation under the microscope by means of microchemical manipulators; those best suited for liquids are distillation at normal or reduced pressure (e.g., in special distillation apparatus holding 0.1 ml., or in fractionation tubes for amounts of a few μl.), liquid-liquid extraction procedures in separatory funnels, or in extraction apparatus, and separations by gravity. The most important physical constants for solid substances are melting point (in capillaries or on the hot stage according to Kofler and Weygand), sublimation point (Kofler and Fischer), refractive index (Becke-line method), specific rotation, and optical structure if the substance is available in crystalline form. For liquid compounds the physical constants are the boiling point (Emich), refractive index (with Abbe-refractometer, "schlieren"-method, or Becke-line method), specific gravity (with milligram or centigram pipettes) and viscosity (Mouquin and Alber).

During the investigation of the physical constants two special studies became necessary, the first of which was a comparison of the numerous microextractors for solids. It was found that none of them was applicable for general purposes, since each was designed for a special case only. On the basis of this work, a general microextractor can be developed, or the most suitable one for a given case selected. The second study was on the specific gravity determination of hygroscopic or very volatile liquids. Ordinary micropipettes were fitted with caps over both ends, thus eliminating troublesome influences during the period of weighing. The milligram pipettes allowed the measurement of any given small amount of liquid so that the difficulties in adjusting very mobile liquids to a single mark were overcome.

The next step is the elementary analysis which must be reliable even in the presence of such elements as mercury, arsenic, selenium, bismuth, etc., since compounds containing these elements are often encountered in the analysis of pharmaceutical preparations. The tests for the elements

allow estimations to within 5% of the quantities present, so that the compounds may be classified within a narrower range. This estimation also permits the study of the influence of interfering substances; it indicates whether an element is present as a trace (below 1%), and thus eliminates misinterpretations due to impurities, a condition which must be considered in testing biological substances. (It also allows the selection of the correct amount of sample for a quantitative organic microanalysis.) A simple, inexpensive balance, modified according to the principle of Salvioni, may be used for the rapid weighing of samples from 0.5 to 1 mg. An approximate determination of ash or residue within 5 to 10% may be performed instead of the ignition test, since the former includes the information given by the latter. If the presence of a salt or an inorganic by-product is indicated, the inorganic elements may be estimated in this residue according to the semi-quantitative procedure of Benedetti-Pichler and Spikes.

As found by the elementary analysis of over 500 substances, the sodium fusion is considered more reliable than other recently described procedures. From 0.2 to 0.5 mg. of the substance are introduced to the bottom of fusion tubes with two bulbs, both of which contain metallic sodium. By heating the upper bulb first, even liquid samples will be decomposed without loss, since the vapors have to pass the hot sodium. After leaching and filtering through microfunnels by means of centrifugal force, the filtrate is brought to a definite volume in calibrated microcentrifuge cones. Aliquot portions of this slightly alkaline solution are taken for the estimation of the total halogens as silver halides, sulfur as lead sulfide, phosphorus as phospho-ammonium-molybdate, and nitrogen as Prussian blue. The precipitates are collected in the cylindrical ends of microcentrifuge cones, and, after centrifuging over a standardized period of time, compared with precipitates obtained from known amounts of the elements in question. The estimations are accurate to within 5% (absolute) and the time consumed will, in the average, not exceed one half hour for all of the tests. The differentiation and separation of chlorine, bromine, and iodine, which are present as silver halides after the estimation, are accomplished by the differences in their solubilities in am-

monium carbonate and ammonia, provided the ratio of the elements is approximately 1 : 1 : 1.

Another procedure for elementary analysis is recommended when the elements are present in the lower range of percentages, between 1 and 5%, or if certain interfering elements must be considered, such as arsenic or selenium. It consists of the micro Carius test as applied by Emich for the identification of sulfur, but in a slightly modified form. The substance is heated with concentrated nitric acid in a sealed capillary tube of Pyrex glass. The cool digest is used for the precipitation of the sulfuric acid formed as barium sulfate, phosphoric acid as phospho-ammonium-molybdate, arsenic acid as the similar arsenic complex, in elementary form by means of the Bettendorff reaction, or as sulfide, selenium in its elementary form after reduction, bismuth as the sulfide, etc. The length of the column of a precipitate may be compared with a precipitate from known amounts in the capillary tubes or after transfer into the previously mentioned microcentrifuge cones. This sealed tube procedure prevents any loss of material during the decomposition and makes possible not only the identification of traces, but also their rough estimation.

From the results of these classification tests the possibilities as to the identity of the substance are narrowed down considerably. The final identification is accomplished through the preparation of suitable derivatives for which no definite procedures can be recommended; in fact, nearly all known microchemical techniques will play an important part at one time or another. In special cases the exceptional behavior of the substance necessitates certain precautions, for example, in the handling of hygroscopic liquids. The comparison of numerous microtechniques for removal of moisture leads to the selection of the most suitable procedure according to the amounts of sample available (decigram, centigram or milligram procedure). The distillation from the drying agent which is added for the removal of the moisture is carried out under complete exclusion of moist air and with consideration of the ratio of volume of sample to surface of apparatus. In some instances the efficiency of nitration

procedures is impaired if the influence of moisture upon the hygroscopic liquid is not carefully prevented.

As the final step, the determination of the physical constants of the derivatives allows the conclusive identification of the substance. The identity may be confirmed by means of color tests as developed by Feigl and co-workers, which, incidentally, are of minor importance in the first steps of the scheme because of the considerable effects of small amounts of by-products on the color development.

Although these studies are still in progress they have already demonstrated that microprocedures can be substituted for macroprocedures in the comprehensive schemes of organic qualitative analysis. The chief advantage, in addition to the saving of time and expense, is that the microtechniques are the only ones applicable when the substance is very difficult to isolate or obtain.

Proteolytic Activity of Plasma during Tumor or Embryonic Growth in Rats.—LEOPOLD WEIL AND MARY A. RUSSELL. (*Journal of Biological Chemistry*, **126**: 245, Nov. 1938.) It is of importance in working in small animals such as rats to have delicate and refined methods, so micromethods in a few drops of blood for the estimation of the activity of the enzymes peptidase and proteinase are described. The aminopolypeptidase enzyme activity of rat blood plasma remains constant during the growth of transplantable rat cancers. This enzyme has an optimum at pH 7.5. Blood plasma and serum proteinases exhibit optimal activity at pH 7. Blood serum has a slightly higher enzyme activity than plasma prepared from the same blood. During cancer growth or pregnancy in rats, the blood plasma enzyme proteinase decreases considerably. When the tumor is removed by operation, or after termination of pregnancy, the enzyme proteinase rapidly returns to the normal level. Normal and tumor-resistant rats show constant plasma proteinase and aminopolypeptidase activities over long periods of time. There is considerable proof that the processes of cancer growth and pregnancy in animals show a similarity of biochemical and enzyme effects.

STATED MONTHLY MEETING, NOVEMBER 16, 1938.

The regular monthly meeting of the Institute was called to order at 8:20 o'clock, by Mr. W. Chattin Wetherill, Vice-President. He reported that additions to membership since the last report were as follows:

Active	32
Associate	36
Student	320
Total	388

Announcement was also made of the Christmas week lectures on the James Mapes Dodge foundation which will be held on Wednesday, Thursday and Friday afternoons, December 28, 29 and 30. Dr. Hugh Stott Taylor of Princeton, New Jersey, will be the speaker and his subject will be "Chemistry for Young Citizens." The cost for the series will be one dollar; single lectures, fifty cents.

Mention was also made that the Bartol Research Foundation will release several stratosphere balloons from the roof of the Institute's building on Saturday morning, November 19, at 10 o'clock, weather permitting.

The Chairman then introduced the speaker of the evening, Dr. G. P. Harnwell, Director of the Laboratory of Physics of the University of Pennsylvania. His subject was "Our Knowledge of Atomic Nuclei." The various contributions of the field of atomic physics to our civilization were considered and the methods and results of atomic research were briefly summarized. The modern problems of chief interest to pure science are those concerning the central atomic core or nucleus. The methods of investigating these were reviewed and our present views concerning nuclei were presented. The interesting possibilities for using the results that have been achieved to date as tools in pure and applied science were briefly considered. The subject was illustrated by lantern slides and experiments.

After a brief discussion the thanks of the meeting were conveyed to Dr. Harnwell.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE OF SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 9, 1938.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 9, 1938.

MR. EDWARD L. FORSTALL *in the Chair.*

The following report was presented for final action:

No. 3056: Process for Decorating Metals.

This report recommended the award of an Edward Longstreth Medal to Jesse E. Stareck, of Waterbury, Connecticut, "In consideration of the development of a new technique for the study of electrode phenomena encountered in the electrolysis of water solutions and the discovery of a new method applicable to the art of coloring metals."

JOHN FRAZER,
Secretary to the Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 768 readers made use of the facilities during the twenty-six days of October.

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BOOK REVIEWS.

FUNDAMENTALS OF ELECTRICITY AND MAGNETISM, by Leonard B. Loeb. Second Edition, 554 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.00.

A rather difficult and complicated problem faced the author of this book when he set out to produce a text and reference work incorporating the fundamentals of electricity and magnetism in a quantitative treatment. How well the author succeeded can be seen upon examination of this book.

It is now in its second edition, the first having appeared in 1930. The outstanding features are: a presentation of physical laws and quantitative treatment of phenomena without giving the impressions that equations are empirical; equations and relationships are justified on the basis of fundamental experiments, or where the expression is derived, a derivation; a clear and concise form. In other words, the issue is squarely faced that the application of physical laws in practice should be backed up by an intelligent background leaving no possibility for chance to exercise its effect contrary to the desired ends. It can easily be seen that it was no little task to accomplish this in a fundamental form, using mathematics of the grade possessed by those prepared to study the subject, and at the same time to keep the presentation from being dry.

The plan of the work is similar in progression to others. It differs in that the approach to electricity is through magnetism to electric currents and then proceeds through electric resistance, Ohm's law, liquid conductors and electrolysis, thermoelectricity—all before the treatment on static electricity. After this comes electromagnets, induction, electrical measurements, alternating currents, the ratio of electromagnetic and electrostatic units, discharge through gases and atomic structure, and the photoelectric and thermionic effects. There is included a simple and clear introduction on Maxwell's theory of electromagnetic waves, a discussion of the theory and the use of Helmholtz coils, and simplified shorthand methods for the solution of circuit equations. Those who are familiar with the first edition of the book will find many additions and revisions bringing it up to date both from the standpoint of subject matter and the reflection of teaching experience.

In the back of the book some seventy pages are devoted to carefully selected and composed problems that give a thorough exercise on the knowledge gained, in the way of practical application. Answers to the problems are shown. There are

also author and subject indexes, the latter particularly well done. The book contains a thorough treatment and comprises an excellent reference.

R. H. OPPERMANN.

EDISON'S OPEN DOOR, by Alfred O. Tate. 320 pages, plates, 14 × 22 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $3.00.

Alfred Tate, the author of this book, was secretary to Thomas A. Edison during some of the latter's most active years. As such, and especially because he was an officer of many of the Edison companies during these years, his statements are authoritative with respect to this side of Edison's work. The inventive work of Thomas Edison is well known. The phonograph and the incandescent lamp are attributed widely to his ingenuity, and somewhat less known are Edison's developments in other diverse fields. But Edison's business abilities and his business ventures have been needed to be brought more to public attention. While these were perhaps not as spectacular in a popular way, in a sense at least, they were equally as important. The author, in this book, attempts to satisfy this need.

The manner in which this book is written creates a warmth of feeling with the author who brings the reader closer to Edison and to the times in which the story takes place. The story starts with the early business activities of the author, as telegraph operator in Canada and Virginia. Subsequent to this he became connected with the Edison interests under the late Samuel Insull. This was after the time of the invention of the phonograph and when the incandescent lamp was ascending in development, the early eighteen eighties to the mid-nineties. It was a period of invention and pioneering in finance and one during which the foundation of many of our great industries was laid. Those who are familiar with business history will delight in reading this side of the story. Although Edison's part in this is prominent there are other sides too. It is revealed that Edison as a business man was the same tireless worker. In accordance with popular conception he knew no fatigue limit but at ends of long periods without rest, he slept many hours. He looked upon the earning of money only as a means of forwarding his work for the good of mankind. He did not claim the distinction of a scientist and desired only to be classed as an inventor, of which there were many at this time. The picture of Edison's wild acclaim when he visited Paris during the exhibition is vividly painted.

In one of the many bypaths of the story, the author's impression is given of Samuel Insull after years of intimate acquaintance. This part should be read by many people today.

The book is a narrative of events arranged more or less chronologically, as they occur to mind from recalling the past. Generally the theme runs parallel with the main subject matter of association with Edison, but interwoven are interesting sidelights that make pleasant reading.

R. H. OPPERMANN.

A COURSE OF STUDY IN CHEMICAL PRINCIPLES, by Arthur A. Noyes and Miles S. Sherrill. Second Edition, rewritten. 554 pages, illustrations, tables, 15 × 22 cms. New York, The Macmillan Company, 1938. Price $5.00.

That part of chemical science which treats of the principles which generalize the facts relating to the physical properties and to the reactions of chemical

substances, sometimes called general, theoretical, or physical chemistry, is here called chemical principles. It is to this that the book is devoted. There are nine parts, all limited to the more distinctly chemical sides of theoretical chemistry.

It begins with a presentation of certain fundamental principles relating to matter and energy which underlie both the science of chemistry and the science of physics—the concepts and laws relating to chemical substances, to their elementary composition and atomic constitution, and to the physical states in which they exist. Then there are discussed the foundations of thermodynamics and the application of the laws to physiochemical and chemical changes. Next are developed the molecular, atomic, and ionic theories as to the constitution of substances, mainly through a consideration of the most directly related physical properties of substances as exhibited in their different states of aggregation. Following this consideration is given to laws regarding the pressure, volume, temperature, and molar composition of gaseous substances, and in connection with these laws the theoretical principles from which molecular weights, atomic weights, and molecular formulas are derived. The molecular kinetic theory of gases is also developed.

Solutions are treated with respect to those properties whose magnitudes are determined primarily by the number of molecules present. The application of the molecular theory to solutions is considered. Further discussions on solutions include those of salts, acids and bases with respect to their electrical properties, and ionic theory is developed. The laws of the rates of chemical changes, and the molecular and kinetic theories of chemical reaction rate are considered, followed by the fundamental laws of the equilibrium of chemical changes which are presented mainly from the mass action and phase view-points. Finally there is presented a systematization of the changes in energy, free energy and entropy attending chemical and physiochemical changes in relation to their direction and their equilibrium.

The book offers an intensive training with the end to give that which is essential for pursuing successfully more specialized courses of scientific study or for applying chemical principles to industrial problems. As such, a feature of the text is the work in the nature of problems which are interspersed. They are in this case unusual in that they require clear, logical thinking, not the type merely requiring a substitution of formulas and mathematical operations. The book contains an index of authors as well as subjects.

R. H. OPPERMANN.

HYDROPHOBIC COLLOIDS. Symposium on the Dynamics of Hydrophobic Suspensions and Emulsions, held at Utrecht on the 5th and 6th of November, 1937, under the auspices of The Colloidchemistry Section of the "Nederlandsche Chemische Vereeniging." 181 pages, illustrations, tables, 15 × 23 cms. Amsterdam, D. B. Centen. Price 4 florins.

The papers of the symposium, under the supervision of Prof. Dr. H. R. Kruyt held at Utrecht in Nov. 1937, are representative of a survey of many concepts connected with the stability of hydrophobic colloids. They are contained, together with discussions on each, in this 180 page booklet. The general introductory paper by H. R. Kruyt considers the importance of this class of colloids in the general trend of thought in colloid science, and with respect to mutual

attraction, peptization phenomena, and flocculation. Following this there are papers by Dr. H. C. Hamaker describing the struggle between attractive and repulsive forces in an ingenious graphic manner; Prof. Dr. A. J. Rutgers on the fundamental problem of the electric double layer and behavior in an external electric field which is from his own original point of view; Dr. E. J. W. Verwey who proceeds to the next step and builds the connection between electric properties and colloid stability; Dr. Andr. Voet (replacing Dr. Büchner) telling of the interesting investigations of the Amsterdam laboratory on lyotropic influences applied to hydrophobic colloids; Prof. Dr. H. J. C. Tendeloo discussing the modern conception of the interchange of ions; Dr. J. Th. G. Overbeck on the domain intermediate between lyophobic and lyophlic colloids, protection and sensibilisation; Dr. J. L. van der Minne dealing with the special class of emulsions, where, in the form of an emulsifying agent, a third phase plays a role at the interface between particle and external liquid; and Ir. H. Eilers on technical applications of base materials in emulsified state.

In view of the rapid advancement of this branch of chemistry, these papers are timely and should prove of value to those interested.

R. H. OPPERMANN.

STARCRAFT, by William H. Barton, Jr., and Joseph Maron Joseph. 228 pages, illustrations, 15 × 23 cms. New York, McGraw-Hill Book Company, Inc., 1938. Price $2.50.

It is becoming increasingly popular for everyone, regardless of training or occupation to have a knowledge of the heavens. That great silent space dotted with hundreds of thousands of bodies offers a field for exploration and investigation just crammed full of adventure and thrills. And this can be and is had by all classes of people with very little effort. According to the degree of knowledge already possessed by those who would enjoy this opportunity, books of a different grade are of use. The book at hand is one for beginners, old as well as young. The person seeking to know the world around him may, with the suggestions offered here, follow the paths that the early pioneers of astronomy trod. It will be recalled that these skygazers were greatly handicapped by lack of knowledge as well as instruments. The authors of this book have seized on the methods used then and this coupled with modern elementary knowledge of the sky, have produced a book that any beginner can understand.

The introductory chapter discusses star light and sky sights, mentioning the number of visible stars, the constellations, planets, and galaxy. After this there comes an explanation of star charts which is an ingenious method to show where to point in the night sky to locate and identify any prominent constellation. The constellations formed by the brighter stars are then described one at a time, the ancient stories from Greek mythology are briefly mentioned, and important facts obtained by modern astronomy are given. This part of the book tells how to observe with the unaided eye as well as with field glasses and a telescope.

What may be termed the second part of the book describes how to make sky charts, observation of meteors and their paths and speed, the elements of navigation, the solar system and how to make a model, how to measure distances with shadows, the construction of a simple sun dial, the construction of a telescope, and the use of pictures in studying the sky.

The book is exceptionally clear and interesting. The paper used is of good quality and the illustrations well done. It is a book anyone can enjoy regardless of whether the various devices suggested are constructed or not. Their construction, it should be mentioned, is simple and inexpensive.

R. H. OPPERMANN.

STRUCTURAL DESIGN, by Carlton Thomas Bishop. 254 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1938. Price $3.50.

Here is a book that is planned in a quite different manner from that of the usual textbook in structural engineering. It has for its purpose the presentation of fundamental principles to engineering students who have some knowledge of statics as a prerequisite and who follow the prescribed course of the author. He states: "It is felt that these principles (of design) can be explained best in their application to detached members without regard to their interrelation with other members of a structure. In this manner the student is enabled to concentrate on a few new conceptions without obscuring them by practical limitations. The application of these principles is later illustrated by the design of interconnected members of typical structures. This method of presentation emphasizes fundamentals, gives greater variety of problems, and withholds the practical points until they can be better appreciated. The later application of elements of design to typical structures is more interesting and of greater significance than when the complete structures are attempted at the outset. Furthermore, the resulting review is invaluable in fixing the fundamentals in mind."

The author has had some thirty years of experience in teaching the subject along these lines. Each chapter of the book has for its starting paragraph a definition or explanation of what is meant by the main term used in that chapter. There are chapters on shears, bending moments, and stresses which have been included for study or for reference as needed. The book is well illustrated with drawings and curves, and there is a subject index.

R. H. OPPERMANN.

ROUTE SURVEYS, A POCKET BOOK FOR THE SURVEY, DESIGN, AND CONSTRUCTION OF RAILWAYS, HIGHWAYS, CANALS, FLUMES, LEVEES, PIPE LINES, TRANSMISSION LINES, AND OTHER ROUTE CONSTRUCTIONS. 261 pages, illustrations, 11 × 17 cms. New York, The Macmillan Company, 1938. Price $3.75.

The title of this book brings to mind the question that arises with many inquisitive automobile drivers when driving over a road that has recently been straightened by the elimination of a dangerous curve or a curve which necessitated considerable time to drive around. The question is, "Why was this curve made in the first place." The answer is the same to this particular question as with a great many other kinds of route construction projects in the past—that they were then constructed to meet only existing needs with the result that future conditions made them obsolete. Today routes for highways, railways, pipe lines, electric transmission lines, etc., are given careful study with an eye to the future, before actual construction is decided upon.

"Route Surveys" is up-to-date in this respect, presenting the fundamentals underlying modern trends. The reader is started with a brief introduction on the importance of surveys and the selection of routes, before the step-by-step order

of the subject is taken up. The actual survey is begun by a chapter on the reconnaissance wherein all of the topics rightly coming under this heading are considered, including the use of instruments, topography, controlling points, aerial surveys, procedure, finally leading up to the reconnaissance report and what it should cover. Next comes the preliminary survey where information is obtained on one or more of the most promising routes and this is followed by a discussion on the location survey which is the final fitting of the line to the ground. After this there are chapters containing a mass of carefully selected and well arranged explanations and data on simple circular curves, compound and reverse curves, vertical and parabolic curves, spirals, railway track layouts, string lining of curves, excavation and embankment, and rights of way. This may be considered the first part of the book.

The second part of the book deals with construction, its procedure and data pertaining thereto, observations for meridian, and adjustment of instruments. The appendix contains a number of problems referred to each chapter, a usable subject index, and tables arranged to facilitate use covering the wide range of requirements of the civil engineer.

The book is simply written, logically planned, and practical to students, and to practicing engineers as a reference.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Reports: No. 634, Calculation of the Chordwise Load Distribution over Airfoil Sections with Plain, Split, or Serially Hinged Trailing-Edge Flaps, by H. Julian Allen. 16 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

A method is presented for the rapid calculation of the incremental chordwise normal-force distribution over an airfoil section due to the deflection of a plain flap or tab, a split flap, or a serially hinged flap. This report is intended as a supplement to N.A.C.A. Report No. 631, wherein a method is presented for the calculation of the chordwise normal-force distribution over an airfoil without a flap or, as it may be considered, an airfoil with flap (or flaps) neutral.

The calculations are made possible through the correlation, by means of thin-airfoil theory, of numerous experimental normal-force distributions. The method enables the determination of the form and magnitude of the incremental normal-force distribution to be made for an airfoil-flap combination for which the section characteristics have been determined.

A method is included for the calculation of the flap normal-force and hinge-moment coefficients without necessitating a determination of the normal-force distribution.

No. 638, The Influence of Lateral Stability on Disturbed Motions of an Airplane with Special Reference to the Motions Produced by Gusts, by Robert T. Jones. 10 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Disturbed lateral motions have been calculated for a hypothetical small airplane with various modifications of fin area and dihedral setting. Special combinations of disturbing factors to simulate gusts are considered and the influence of lateral stability on the motions is discussed.

The modifications of the airplane include changes of dihedral from 0 to 10 and changes of the weathercock stability from zero to $C_{n_\beta} = 0.137$ (the equivalent of a fin as large as 10 per cent. of the wing area). The positions of the modified airplanes on the lateral-stability charts are shown.

Fin area and wing dihedral were found to be of primary importance in side gusts. It was found that the rolling action of the wing with as much as 5° dihedral was distinctly unfavorable, especially when the weathercock stability was small. It is pointed out that the greatest susceptibility to lateral disturbances lies in the inherent damping and coupling moments developed by the wing.

PUBLICATIONS RECEIVED.

Steller Dynamics, by W. M. Smart. 434 pages, illustrations, tables, 18 × 26 cms. Cambridge, The University Press, 1938. Price $8.50.

The Properties of Glass, by George W. Morey. 561 pages, illustrations, tables, 16 × 23 cms. New York, Reinhold Publishing Corporation, 1938. Price $12.50.

The Book of Time, by Gerald Lynton Kaufman. 287 pages, plates, 15 × 22 cms. New York, Julian Messner, Inc., 1938. Price $3.00.

Introductory Quantum Mechanics, by Vladimir Rojansky. 554 pages, illustrations, tables, 16 × 23 cms. New York, Prentice-Hall, Inc., 1938. Price $5.50.

Procedures in Experimental Physics, by John Strong, and others. 642 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1938. Price $5.00.

Steel and its Heat Treatment. Volume I—Principles, Processes, Control, by D. K. Bullens. Fourth Edition, 445 pages, illustrations, plates, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.50.

American Institute of Mining and Metallurgical Engineers. Transactions, Volume 131, Iron and Steel Division, 1938. 448 pages, illustrations, plates, 16 × 24 cms. New York, Institute

Kurzes Lehrbuch der Physikalischen Chemie, von Dr. Karl Jellinek. Heft I, Grundprinzipien der Physikalischen Chemie, Lehre von den Reinen Stoffen und Mischungen von Nichtelektrolyten (Physikalisch-Chemische Thermodynamik). 314 pages, illustrations, tables, 16 × 25 cms. Deventer, A. E. Kluwer Ltd., 1938. Price 8.50 R.M.

National Research Council. Transactions of the American Geophysical Union, Nineteenth Annual Meeting. Part I, Reports and Papers, Washington, D. C., General Assembly and Sections of Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, Volcanology, and Hydrology. 585 pages, illustrations. Part II, Reports and Papers Section of Hydrology and Western Interstate Snow-Survey Conference. 156 pages, illustrations. 2 volumes, 17 × 25 cms. Washington, Council, 1938.

World Economic Unity, by Felix Soron. Appendix to First Edition of Occupational Representation. 176 pages, 15 × 22 cms. Detroit, World Economic Unity Publication, 1938.

U. S. Department of the Interior, Bureau of Mines. Coke and Byproducts Tables, 1937, by H. L. Bennit and M. van Siclen. 29 pages, 31 × 20 cms. Washington, 1938.

U. S. Department of Commerce, National Bureau of Standards. Building Materials and Structures Report BMS2, Methods of Determining the Structural Properties of Low-Cost House Constructions, by Herbert L. Whittemore and Ambrose H. Stang. 18 pages, illustrations—Building Materials and Structures Report BMS3, Suitability of Fiber Insulating Lath as a Plaster Base, by Lansing S. Wells and D. C. Smith. 17 pages, illustrations. Two pamphlets, 20 × 27 cms. Washington, Superintendent of Documents, 1938. Price 10 cents each.

National Advisory Committee for Aeronautics. Technical Notes: No. 669, The Drag of Inflatable Rubber De-Icers, by Russell G. Robinson. 10 pages, illustrations. No. 671, A Method of Rapidly Estimating the Position of the Laminar Separation Point, by Albert E. von Doenhoff. 10 pages, illustrations, No. 672, Flow Observations with Tufts and Lampblack of the Stalling of Four Typical Airfoil Sections in the N.A.C.A. Variable-Density Tunnel, by Ira H. Abbott and Albert Sherman. 17 pages, illustrations. No. 673, The Pressure Available for Ground Cooling in Front of the Cowling of Air-Cooled Airplane Engines, by George W. Stickle and Upshur T. Joyner. 17 pages, illustrations. Five pamphlets, 20 × 26 cms. Washington, Committee, 1938.

Bell Telephone System, Monographs: B-1077, Stability of Two-Meter Waves, by Charles R. Burrows, A. Decino and Loyd E. Hunt. 13 pages, illustrations. B-1082, Transmission Features of the New Telephone Sets, by A. H. Inglis. 23 pages, illustrations. B-1085, Stabilized Feedback Oscillators, by G. H. Stevenson. 17 pages, illustrations. B-1086, Coaxial Cable System for Television Transmission, by M. E. Strieby. 20 pages, illustrations. B-1087, An Experimental Study of the Rate of a Moving Atomic Clock, by Herbert E. Ives and G. R. Stilwell. 28 pages, illustrations. B-1088, The Influence of Moisture upon the D. C. Conductivity of Impregnanted Paper, by D. A. McLean and G. T. Kohman. 18 pages, illustrations. B-1089, Application of Statistical Methods to Manufacturing Problems, by W. A. Shewhart. 24 pages, illustrations. B-1090, An Electron Diffraction Examination of Some Linear High Polymers, by K. H. Storks. 22 pages, illustrations. B-1091, The Mechanism of Hearing, by Harvey Fletcher. 10 pages, illustrations. B-1092, Transmission Theory of Spherical Waves, by S. A. Schelkunoff. 14 pages, illustrations. Ten pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1938.

CURRENT TOPICS.

Westinghouse Ships Giant Time Capsule.—(*Electrical World*, Vol. 110, No. 10.) A tangible record of twentieth century achievements is being preserved for the inhabitants living 5,000 years from now, and life as it now exists can then be clarified when an 800 lb. metal envelope is opened. The Westinghouse Electric & Manufacturing Co. has shipped from its Pittsburgh Plant the huge metal envelope to New York, where it will be deposited 50 ft. in the earth beneath the Westinghouse exhibit at the 1939 New York World's Fair. The 7 ft. 6 in. "Time Capsule" symbolizes the key to the "Philosopher's Stone," for it will contain a cross-section of modern achievements in science and art, as represented by news reels and books reproduced in microfilm and selected products of laboratories, factories and cities. It will also contain the formula for "Cupaloy," the copper alloy of which the capsule itself is made. Cast in seven sections, the Time Capsule is shaped like a torpedo 8 in. in diameter. The objects to be preserved for the scientists of 6939 A.D. will be placed in a 6 ft. inner crypt of heat-resistant glass. A book telling what is contained in the capsule will be sent to the foremost libraries, museums and repositories of the world so that the future scientists will know where to find the messages of the twentieth century.

R. H. O.

The Examination of Some Tinned Foods of Historic Interest.—J. C. DRUMMOND AND W. R. LEWIS (*Chemistry and Industry*, Vol. 57, No. 35.) The authors in Part I of their paper (Historical Introduction) give some very interesting information on the early canning of foods. It was undoubtedly Nicholas Appert working quietly in his little house at Massy during the troubled years of the end of the 18th century who laid the foundations of our modern canning industry. His preparations, a wide range of meats, vegetables and fruits, and even milk, were tried out experimentally by the French Navy about 1806 and apparently proved successful. A few years later John Hall and Bryan Donkin developed a process in England, based on that of Appert, but they saw a promising future in the use of iron containers instead of glass. In 1810 England granted patents to A. deHeine and P. Durand for the use of iron and tin containers but neither engaged in so preserving food commercially. Donkin and Hall's preserved foods met with much favor in the British Navy on ships and land stations, not only for its

well preserved state but for preventing and curing seamen's diseases. Large amounts of such foods were supplied to the Admiralty Victualling Depot at Deptford in 1818. They gave satisfaction in exploration expeditions in 1815, 1819, 1824 and 1826. Two tins of the latter expedition which was to the Sandwich Isles have a recorded history. One was opened in 1846 before the chemistry students of Guy's Hospital. It seemed perfectly preserved. In 1867, the remaining tin was opened at the Society of Arts. The contents were in a partially decomposed condition due, it was claimed, to rust having perforated the can some years before. It was then suggested that cans be lacquered or painted on the outside to prevent rusting.

R. H. O.

City Air Searched for Sulphur Fumes.—(*Heating, Piping and Air Conditioning*, Vol. 10, No. 9.) Results of a 15 month survey to determine the average amounts of sulphur gases in the air of American cities are announced by Air Hygiene Foundation and Mellon Institute. More than 50,000 separate air tests were made by six chemists driving a fleet of cars equipped like "traveling laboratories." They canvassed industrial and residential centers throughout the east, south, and mid-west. Most of the tests covering all hours of the day and night and all seasons of the year, were made in five metropolitan districts. Of these, St. Louis shows 0.128 and Washington 0.009 (highest and lowest) average parts of sulphur dioxide per million parts of air within a 15 mile radius. The figures are of no significance from a public health standpoint, according to hygienists connected with the investigation, as they are too small. The survey showed that the home fires are among the large contributors to sulphur pollution, particularly in districts using coal of high sulphur content. The type of coal burned in a locality was mirrored in the results of the study. The fuel factor also explains why sulphur pollution in most districts was approximately 50 per cent. higher in the heating season than in the summer months. Some industrial operations also discharge sulphur fumes unless properly safeguarded. A close relationship was found between wind velocity and the amount of sulphur dioxide in the air. The higher the wind the cleaner the air. Fogs catch and "store up" the sulphur fumes. Some of the highest concentrations were noted on foggy nights.

R. H. O.

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